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Actinomycete Distribution in Northern Green Bay and the Great Lakes. Taste and Odor Relationships in Eutrophication of Nearshore Waters and Embayments

Michigan Dept. of Natural Resources, Lansing

Prepared for

Environmental Protection Agency, Chicago, Ill. Enforcement Div.

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ACTINOMYCETE DISTRIBUTION IN NORTHERN GREEN BAY AND THE GREAT LAKES

TASTE & ODOR RELATIONSHIPS TO EUTROPHICATION OF NEARSHORE WATER & EMBAYMENTS

U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION V ENFORCEMENT DIVISION
GREAT LAKES INITIATIVE CONTRACT PROGRAM

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16. ABSTRACT

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This report is submitted in fulfillment of an EPA project, Contract Number 68-01-1885, by Michigan Department of Natural Resources, Bureau of Environmental Protection at Lansing under the support of the Environmental Protection Agency. Work was completed as of January 1975.

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ACTINOMYCETE DISTRIBUTION IN NORTHERN GREEN BAY AND THE GREAT LAKES

Taste and Odor Relationships in Eutrophication of Nearshore Waters and Embayments

by
Dennis P. Tierney
Richard Powers
Theodore Williams
S. C. Hsu

MICHIGAN DEPARTMENT OF NATURAL RESOURCES
BUREAU OF WATER MANAGEMENT

AND

MICHIGAN DEPARTMENT OF PUBLIC HEALTH
BUREAU OF WATER MANAGEMENT

In fulfillment of
EPA Contract No. 68-01-1885
for the
Enforcement Division
U.S. Environmental Protection Agency
Region V
Chicago, Illinois 60604

Great Lakes Initiative Contract Program
Report Number: EPA-905/9-74-007
EPA Project Officer: Howard Zar

July 1976

This report has been developed under auspices of the Great Lakes Initiative Contract Program. The purpose of the Program is to obtain additional data regarding the present nature and trends in water quality, aquatic life, and waste loadings in areas of the Great Lakes with the worst water pollution problems. The data thus obtained is being used to assist in the development of waste discharge permits under provision of the Federal Water Pollution Control Act Amendments of 1972 and in meeting commitments under the Great Lakes Water Quality Agreement between the U.S. and Canada for accelerated effort to abate and control water pollution in the Great Lakes.

This report has been reviewed by the U.S. Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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Actinomycetes have been suspected of causing earthy-musty odors in water since the turn of the century. This study concentrated on the relationship of actinomycetes in northern Green Bay and the Great Lakes contiguous to the State of Michigan with the trophic status and point source inputs in the nearshore waters.

Five field surveys were conducted at eight stations in northern Green Bay during April-October of 1974. Additionally, twenty-six municipal water supply facilities collected untreated water samples in the spring, summer and fall of 1974. Actinomycete population structure, abundance and history of odor occurrence was determined for each location. Trophic status data was based on simultaneous physical-chemical and phytoplankton surveys in northern Green Bay and from recent limnological literature for the Great Lakes.

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CONCLUSIONS

Actinomycete populations are higher in Green Bay and other areas of the Great Lakes which are nutrient enriched. These areas have generally had a history of earthy-musty odor occurrences. Laboratory actinomycete growth was greater in water collected from eutrophic areas. The percent of Streptomyces in actinomycete populations from these nutrient enriched areas of the Great Lakes with a history of odor problems are higher than areas with an absence of odor occurrences.

The results of this investigation support the hypothesis that earthy-musty odor occurrences are casually-linked to the eutrophication of Green Bay and other areas of the Great Lakes. They also suggest that in the nutrient enriched areas, actinomycete numerical increases and percentage increases of the genus Streptomyces in the actinomycete population are responsible for the earthy-musty odors.

Actinomycetes are able to use a variety of organic substances as carbon sources. Phenol, cellulose, secondary municipal wastewater treatment plant effluent, paper mill effluent and dead algal cells increased actinomycete growth. Actinomycetes cultured on some of these organic materials also produced strong earthy-musty odors.

Reduction of inputs of inorganic and organic nutrients should reduce the nutrient and substrate availability to actinomycetes. This should result in improved water quality with fewer earthy-musty odor problems in the Great Lakes.

RECOMMENDATIONS

1. Inorganic nutrient inputs to the Great Lakes should be reduced to the lowest practicable level. The increased nutrient inputs are mainly responsible for increased algal populations which increase the dissolved and suspended organic content of the lakes. Actinomycete abundance, and often the earthy-musty odor, are greater in nutrient enriched areas of the Great Lakes. Reduction in loadings of essential algal nutrients to the Great Lakes should indirectly assist in actinomycete population regulation.

2. Organic nutrient inputs to the Great Lakes should also be reduced to the lowest practicable level. Laboratory studies show that organic materials in municipal and paper processing effluents are utilized as a nutrient source by actinomycetes. Therefore, increased abundance of organic materials in the Great Lakes stimulates actinomycete population growth which often have associated earthy-musty odors.

INTRODUCTION

The Laurentian Great Lakes constitute the largest body of fresh water on the earth's surface (Beeton, 1965; Beeton and Chandler, 1966). Dating back to the mid-eighteen hundreds, the lakes have been used for commercial and industrial-municipal water supply purposes. Historically, the Great Lakes have served as a high quality potable water supply to many Michigan communities. The water was clear and relatively free of objectionable microorganisms, tastes and odors. Recently, a number of communities have reported an over-all decrease or erratic seasonal fluctuation in water quality; requiring increased water treatment (Courchaine et al., 1972).

Green Bay (Lake Michigan) is the largest embayment on Lake Michigan. It is approximately 120 miles in length and approximately 20 miles in width. The major tributaries enter the southern one-third of the bay. The Fox, Oconto and Peshtigo Rivers in Wisconsin along with the Menominee River located on the Wisconsin-Michigan border account for 88 percent of the annual discharge to Green Bay (U.S. Department of the Interior, 1968a). The southern one-third to one-half of the bay exhibits water quality conditions reflecting excessive concentrations of plant nutrients, organic matter and suspended solids (Patterson, 1975). In the summer months, algal blooms frequently occur over an extensive area and in the winter depressed dissolved oxygen levels occur under ice cover (Sager and Wiersma, 1972; Scott et al., 1957). The Fox River is the major tributary of Green Bay and enters the bay at its southernmost point. Along the last 40 miles (64 km) of the river is the largest pulp and paper industry in the world (Billings, 1966). Industrial and domestic wastes have severely polluted the lower Fox River and lower one-third of Green Bay (Schraufnagel et al., 1968; Howmiller and Beeton, 1970; and Sager and Wiersma, 1972). The impaired water quality of southern Green Bay is a direct result of the past social and economic activity in the immediate watershed and major tributaries.

Industrial and municipal waste discharges are not confined to the southern portion of Green Bay. The northern portion, in addition to receiving natural organic inputs from non-industrialized streams with relatively undeveloped watersheds, receives input (loading) from nine wastewater treatment plants (WWTP) and two paper mills. Both paper mills and a municipal WWTP discharge to the Escanaba and Menominee Rivers. The municipal WWTP of Escanaba and Gladstone discharges into Little Bay de Noc. There are other smaller discharges as well. The water quality of northern Green Bay is considered good today, but continued discharge of municipal and industrial effluents may threaten future water quality.

Actinomycetes have been implicated as one of the agents responsible for the decrease in water quality in the Great Lakes and increased water purification plant treatment. A few localized areas, namely southern Lake Michigan in the vicinity of Chicago, Illinois (McMillan et al., 1972), Lake Erie near Cleveland, Ohio (Potos, 1968) and Mt. Clemens, Michigan, on Lake St. Clair (Hansen, 1964) have reported taste and odor problems and identified actinomycetes in the raw water supply.

Similar odors have occurred (1969-72) at objectionable intensities along the entire western shore of northern Green Bay; including the water purification facilities at Gladstone, Menominee and Escanaba, Michigan. An "objectionable" odor intensity is the level of odor in drinking water at which people begin to register complaints with water department personnel. This level varies from community to community depending on the water quality people have previously experienced, the odor type and past exposure to odor outbreaks. Water plant supervisors have estimated that complaints about odors begin at a threshold odor number (TON) of between 3 and 6. Earthy-musty odors were noted at Escanaba (1969) for the first time in the recorded history (85 years) of the three water supplies in northern Green Bay. By 1972 all three communities had experienced this phenomenon. The odor was usually described as earthy or musty. Although very intense at times, the odor levels fluctuated. Odors reached a maximum in February-April of 1972 at Escanaba (Figure 1). Field and laboratory investigation by the Michigan Water Resources Commission and the Michigan Department of Health (1972) suggested the objectionable odor was related to the presence of actinomycetes in northern Green Bay.

Actinomycetes were initially isolated from fresh water ecosystems in the early 1900's (Adams, 1929). Interest in them was due to the occurrence of earthy-musty odor in drinking water and fish taken from certain rivers and lakes. As such, they have been suspected of causing earthy-musty odors in water for many years (Adams, 1929, 1931; Thaysen, 1936; Isavenko and Egorova, 1941; Ferranola, 1949). Silvey and his co-workers (Silvey, 1953; Roach and Silvey, 1958; Silvey and Roach, 1959; Silvey et al., 1959) have extensively studied the morphology, life cycle and nutrition of actinomycetes. They conclude that actinomycetes are the major cause of earthy-musty odors in fresh water and can utilize almost any organic compound containing sufficient organic carbon and nitrogen, including dead algal cells.

It should be noted that actinomycetes are not the only source of odor problems. There are algal species capable of producing the same odors. Blue-green algal species have produced the characteristic odor under laboratory conditions (Gerber, 1967; Safferman et al., 1967; Medsker et al., 1968). Two compounds, geosmin and methylisoborneol, have been separated from actinomycete cultures and identified as the chemical agent responsible for the odor (Gerber, 1967). Geosmin has also been identified as a metabolite of several species of blue-green algae (Safferman et al., 1967; Medsker et al., 1968).

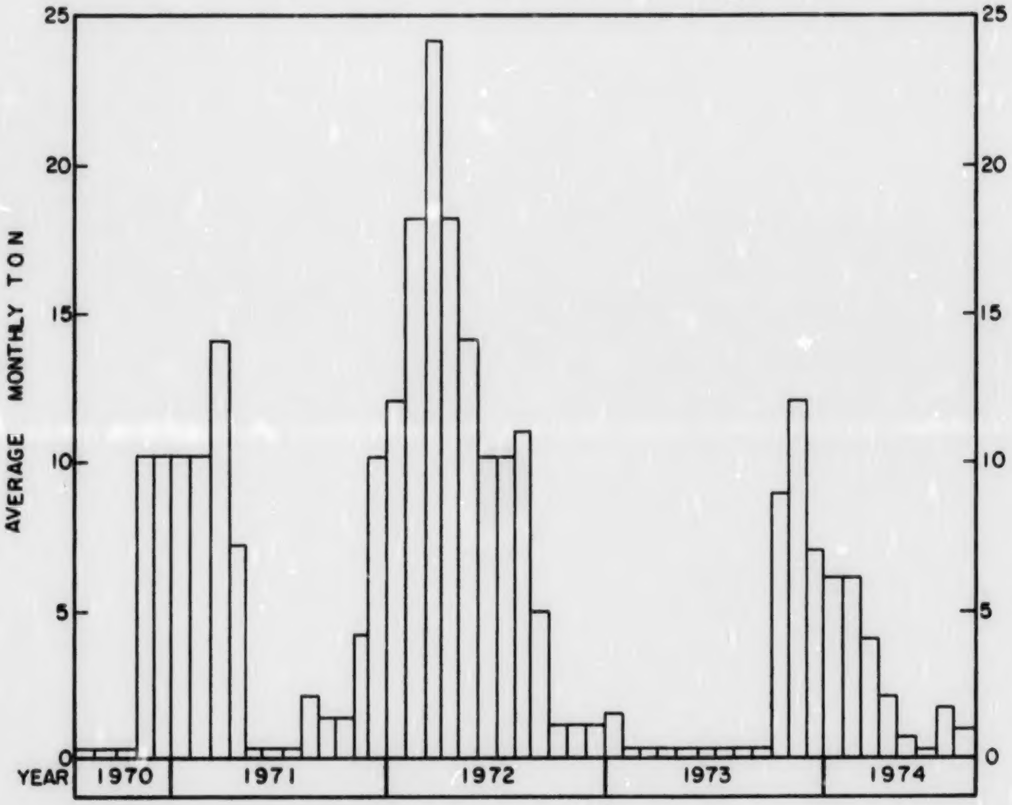


FIGURE 1. MONTHLY THRESHHOLD ODOR NUMBER AVERAGES FOR THE ESCANABA MUNICIPAL WATER SUPPLY INTAKE WATER, 1970 – 74.

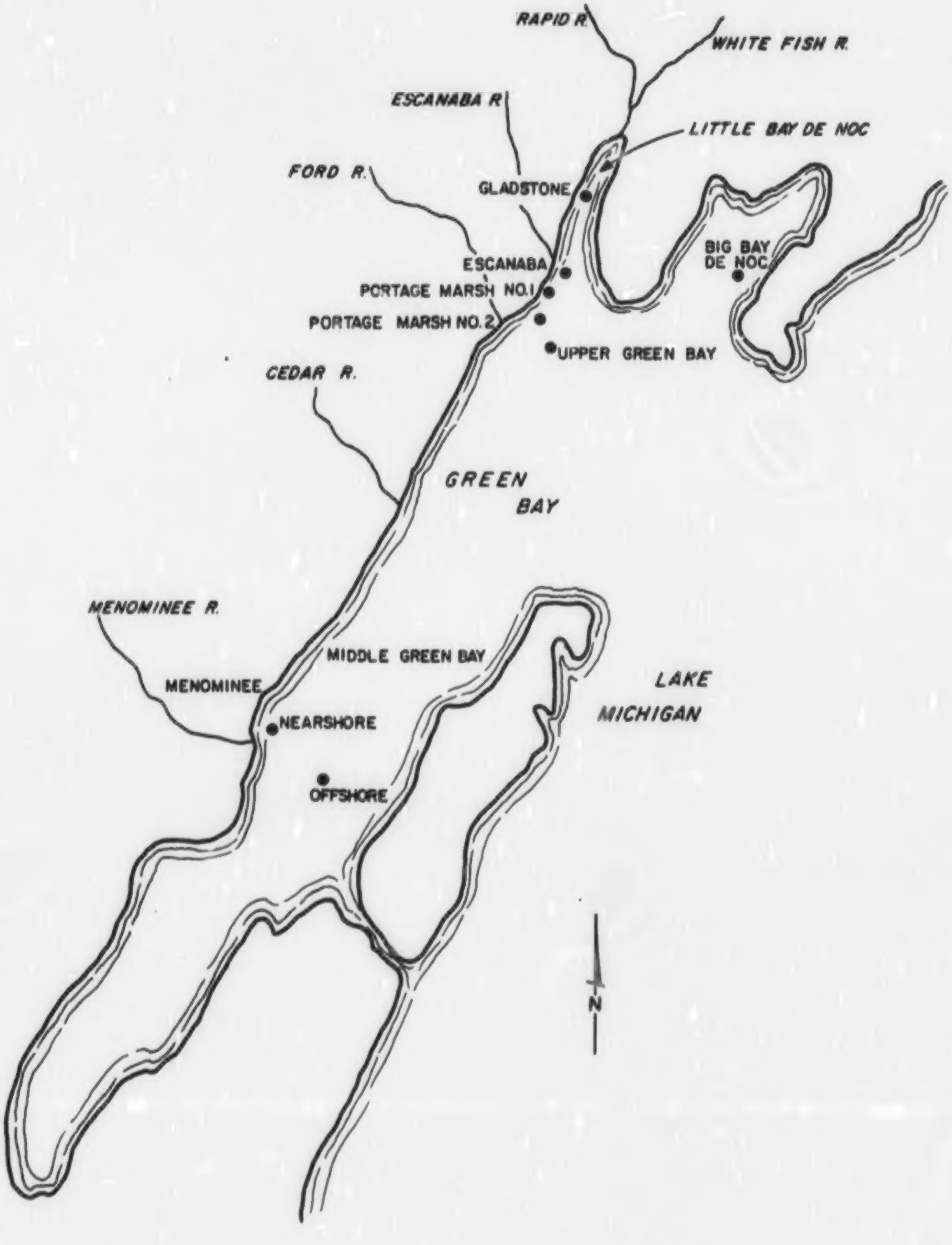
This study concentrated on the relationship of actinomycetes and water quality in northern Green Bay (Lake Michigan) to taste and odor occurrences in the municipal water supplies of Gladstone, Escanaba and Menominee, Michigan. Odor problems in communities obtaining water supplies from the Great Lakes contiguous to the State of Michigan (Superior, Michigan, Huron, Erie and connecting waterways; St. Clair River, Lake St. Clair and Detroit River) were also investigated in relation to the Green Bay problem. The major focus was on the occurrence and origin of biological taste and odor problems in Green Bay and the other Great Lakes. That is, where are odor problems located and how are the areas experiencing odor outbreaks ecologically different from locations without odor occurrences? What can be done to alleviate these odor problems?

MATERIALS AND METHODS

Five surveys were conducted (April, May, July, September, and October of 1974) at eight stations in northern Green Bay (Lake Michigan). Stations were located in the vicinity of water purification plant cribs for the communities of Gladstone, Escanaba, and Menominee, Michigan (Figure 2). Background stations were established in Big Bay de Noc, Mouth of Little Bay de Noc and approximately two miles offshore of Menominee, Michigan. Two additional stations were established in Portage Marsh located south of Escanaba, Michigan. Specific station locations are given in Appendix A. Hydrochemistry (Appendix C and D) and phytoplankton (Appendix E and F) surveys of northern Green Bay were also conducted to provide data on the trophic status of this area.

In order to comparatively assess the situation in northern Green Bay, data from other areas in the Great Lakes were necessary. Since little information was readily available in the literature (see Bibliography-Appendix A), it was necessary to directly gather it. Baseline data was collected on actinomycete abundance and population structure in the nearshore waters of the Great Lakes contiguous with the State of Michigan. Questionnaires on water quality were sent to 52 Michigan communities using the Great Lakes as a municipal water source. The number and location of communities using the Great Lakes, the incidence of odor outbreaks and type of outbreak were determined by this questionnaire. Forty-five of the water plants responded to the questionnaire. Twenty-seven (62 percent) reported either grassy, fishy or musty-earthy odors occurring at some period of the year. The vast majority (22 out of 27) reported odors of a musty-earthy character. The facilities reporting odor problems are located in five specific geographical areas (Figure 3): 1) Southern Lake Michigan; 2) Green Bay (Lake Michigan); 3) Saginaw Bay (Lake Huron); 4) St. Clair River-Lake St. Clair - Detroit River; and 5) Lake Erie.

Twenty-six (26) municipal water supply facilities were selected for further study (Figure 3). They supplied untreated water samples in spring (April 29), summer (August 19) and fall (October 14). The actinomycete population structure and abundance was determined for each sample. Fourteen municipal water supply facilities (Figure 4) supplied raw water for laboratory actinomycete studies, chlorophyll _a_ and total organic carbon analyses.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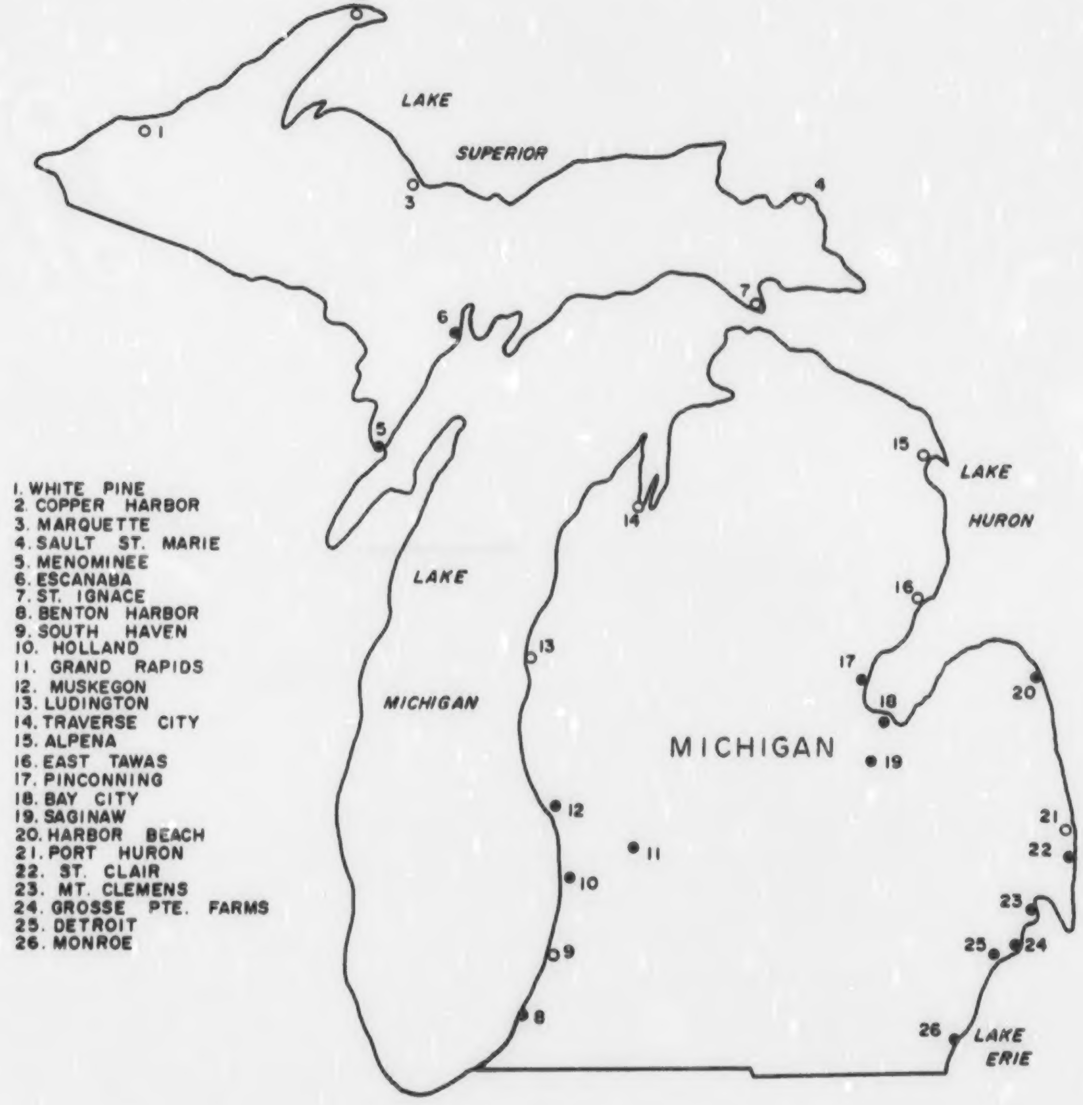
WHITE FISH R.
ESCANABA R.
LITTLE BAY DE NOC
FORD R.
GLADSTONE
BIG BAY DE NOC
ESCANABA
PORTAGE MARSH NO.1
PORTAGE MARSH NO.2
UPPER GREEN BAY
CEDAR R.
GREEN BAY
MENOMINEE R.
MIDDLE GREEN BAY
LAKE MICHIGAN
MENOMINEE
NEARSHORE
OFFSHORE
N

FIGURE 2
GREEN BAY SAMPLING STATIONS FOR ACTINOMYCETE SURVEY


LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
MICHIGAN
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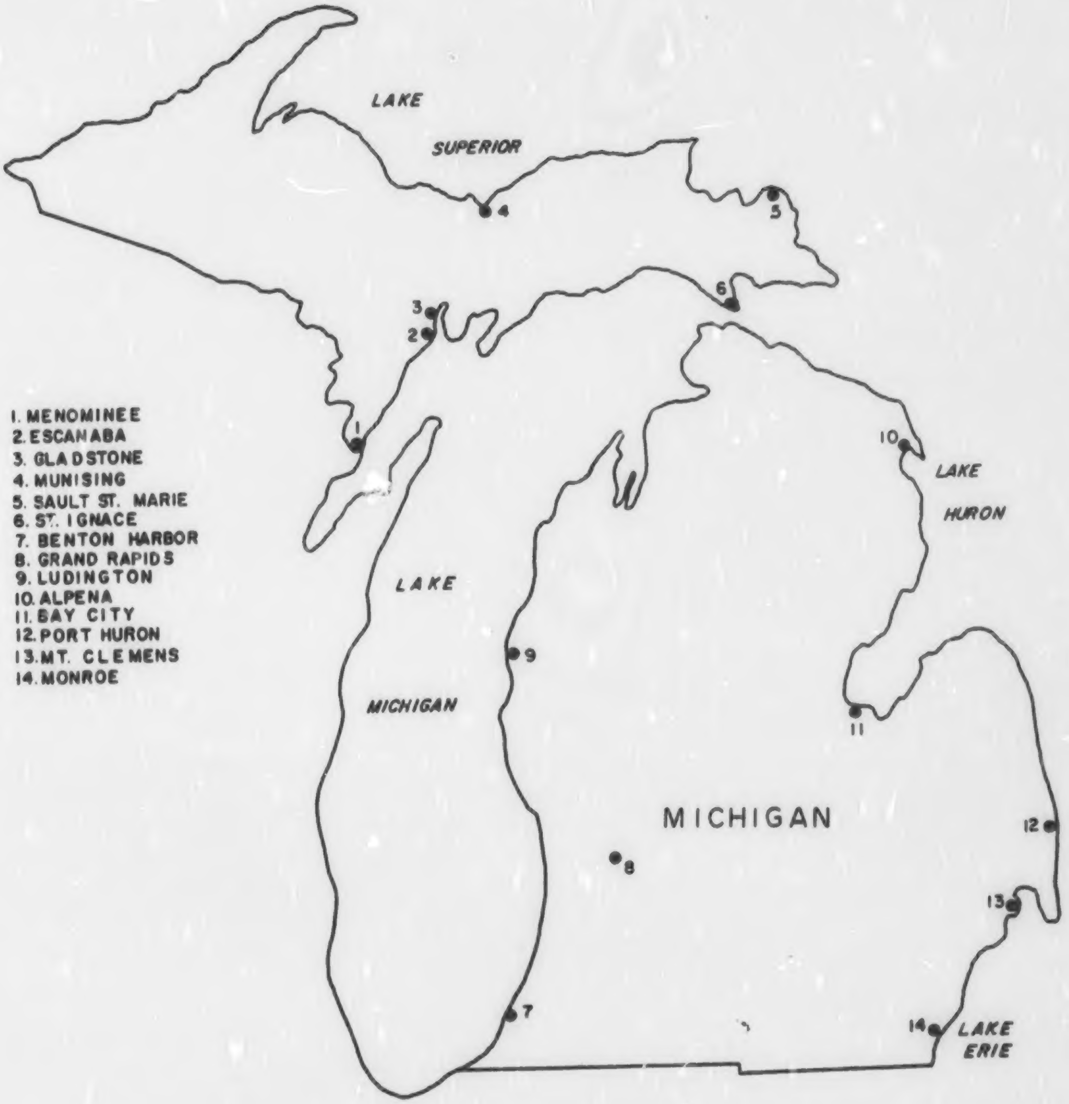
1. WHITE PINE
2. COPPER HARBOR
3. MARQUETTE
4. SAULT ST. MARIE
5. MENOMINEE
6. ESCANABA
7. ST. IGNACE
8. BENTON HARBOR
9. SOUTH HAVEN
10. HOLLAND
11. GRAND RAPIDS
12. MUSKEGON
13. LUDINGTON
14. TRAVERSE CITY
15. ALPENA
16. EAST TAWAS
17. PINCONNING
18. BAY CITY
19. SAGINAW
20. HARBOR BEACH
21. PORT HURON
22. ST. CLAIR
23. MT. CLEMENS
24. GROSSE PTE. FARMS
25. DETROIT
26. MONROE

FIGURE 3. GREAT LAKES LOCATIONS FOR ACTINOMYCETE SURVEY (1974). CLOSED CIRCLES INDICATE LOCATIONS WHERE EARTHY-MUSTY ODORS HAVE BEEN REPORTED.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1. MENOMINEE
2. ESCANABA
3. GLADSTONE
4. MUNISING
5. SAULT ST. MARIE
6. ST. IGNACE
7. BENTON HARBOR
8. GRAND RAPIDS
9. LUDINGTON
10. ALPENA
11. BAY CITY
12. PORT HURON
13. MT. CLEMENS
14. MONROE

FIGURE 4. MICHIGAN WATER PURIFICATION FACILITIES CONTRIBUTING RAW WATER SAMPLES FOR LABORATORY ACTINOMYCETE STUDIES, CHLOROPHYLL *a* AND TOTAL ORGANIC CARBON ANALYSIS.

Field Collection

Water samples from Green Bay were collected in a 6.2 liter plastic kemmerer bottle at selected intervals to obtain information on the vertical distribution of the actinomycete population. The number of samples obtained depended on the presence or absence of thermal stratification. When absent, a minimum of three samples were collected; a meter below the surface, mid-depth and a meter above the lake bottom. When stratification was evident, additional intermediate depths were included in the epilimnion, thermocline and hypolimnion. Samples were placed in sterilized 125 ml glass bottles and refrigerated (4°C). Actinomycete sediment samples were collected with a petite ponar. The top two centimeters of sediment were mixed and subsamples also placed in 125 ml sterile bacteriological bottles. Threshold odor number water samples were also obtained with a kemmerer bottle and placed in glass 1-liter bottles and kept at 4°C.

Laboratory Actinomycete Growth and Analysis

Enumeration and identification of actinomycete populations followed standard bacteriological plating techniques. The medium employed was similar to Lingappa and Lockwood (1962); a chitin agar supplemented with mineral salts which is selective to actinomycetes and those few bacteria that produce the enzyme chitinase (Hsu and Lockwood, 1975).

Growth Characterization

A reliable plate count procedure provides the means to measure changes in actinomycete populations. For purposes of this study, an increase in actinomycete colonies during an experiment is defined as growth. Under controlled laboratory conditions with only a single variable, these changes are interpreted as caused by the experimental variable. While there are problems with this approach, it is currently the only feasible means for studying factors controlling growth under experimental laboratory conditions. However, the plate count might be measuring sporulation activity and be only indirectly related to a net increase in the biomass of the organisms (growth), which would also include such phases as germination and mycelium formation.

In order to interpret results of laboratory actinomycete experiments, a "growth factor" was defined and used for expresssing the extent of growth under any given simulated environmental condition. This growth factor, G_t, is defined by the following equation:

$$G_t = C_t/C_o$$

where t equals the number of days incubation, C_t is the plate count at t days and C_0 is the initial plate count. In some cases control cultures (no treatment) showed some significant growth. In those instances a corrected growth factor was used where the growth factor for the experimental culture was divided by the growth factor for the control culture. This corrects for decreases as well as increases in the control cultures described in the following experiments.

A comparison of growth factors for any given condition (such as temperature, nutrient concentration, etc.) is limited by the following restrictions: 1) the same species must be used throughout; 2) approximately the same initial plate count must be obtained; and 3) the same incubation time must be used. Under these conditions, the growth factor should be directly proportional to the experimental variable's effect on actinomycete growth. A growth factor of greater than one demonstrates growth stimulation and less than one represents inhibition by changes in culture conditions.

In all growth experiments a series of identical cultures were prepared and then incubated for the same period (usually 14 days) at a controlled temperature. Inoculation was done using a constant aliquot volume of the same spore suspension, except in initial experiments where diluted cultures (yeast extract broth) were used for inoculation. The initial experiments required correction since even the small amount of nutrients added along with the actinomycetes caused considerable growth in the experimental controls.

Threshold Odor Number Analysis

Determination of the odor characteristics of Green Bay water followed APHA methods (1971) with some modifications. These were run at room temperature (20-30°C) and odor free water was generated following the advice of A. A. Rosen (Personal communication, 1974 in APHA, 1971). A ten-member panel was selected from the staff and student body of Bay de Noc Community College (Escanaba, Michigan) to assess the odor intensity and character of the water.

RESULTS

General Actinomycete Culture Observations

Actinomycete Recovery

Most actinomycete organisms are slow to appear after plating. The first colonies are visible after 3-7 days incubation (24-28°C). The majority are countable after 14 days; although small increases in counts may be noted as late as three weeks. The observed colony count was assumed to approximate the total actinomycete population of the sample. While this assumption is difficult to validate, laboratory observation and experimentation indicated that the chitin-agar medium was more efficient in terms of recovery of actinomycetes and suppression of non-actinomycete growth than were other media (Figure 5). Generally, 70 to 80 percent of all colonies on the chitin media were actinomycetes while bacteria and fungi often predominated on other media. Recovery of actinomycetes was from three to six times higher on the chitin medium than in the other media.

The colony counts can represent colonies resulting from spores, fractured hyphae or a mixture of both. A direct identification of colony origin is not easily obtainable. However, microscopic examination of slides prepared from fresh enriched cultures of several species indicate that spores were many times more abundant than were fractured hyphal material. This would indicate that most of the colonies resulting from the inoculation of medium with such a culture develop from spores rather than hyphal material.

Isolate Identification and Characterization Enumeration

Actinomycetes cultured on the chitin agar medium are characterized by clear zones around the colony in the otherwise cloudy medium (Figure 6). Recognition of actinomycete colonies requires experience. Suspect colonies can be transferred to various nutrient agars and, if they are actinomycetes, should produce specific characteristics. Since it is time consuming, such verification is not normally included in routine actinomycete enumeration and identification. Occasionally, microscopic examination for hyphae development is required. Organisms giving mucoid colony growth without detectable hypha development were judged to be bacterial rather than actinomycetale. Counting precision for split samples of pure cultures was approximately ± 10-30 percent. Counts are expressed as colonies per ml of water sample or colonies per dry weight of sediment.

Determination of actinomycete isolates to the species level is an involved, time-consuming process. In addition, actinomycetale group taxonomy is confused to the point of debate over whether large groups of organisms should be included in the order. There also exist several different proposed classification schemes within the general order. For the purposes of this study, isolates were generally defined only with respect to the genera usually found in the samples. These include Streptomyces, Micromonospora and Nocardia which were defined

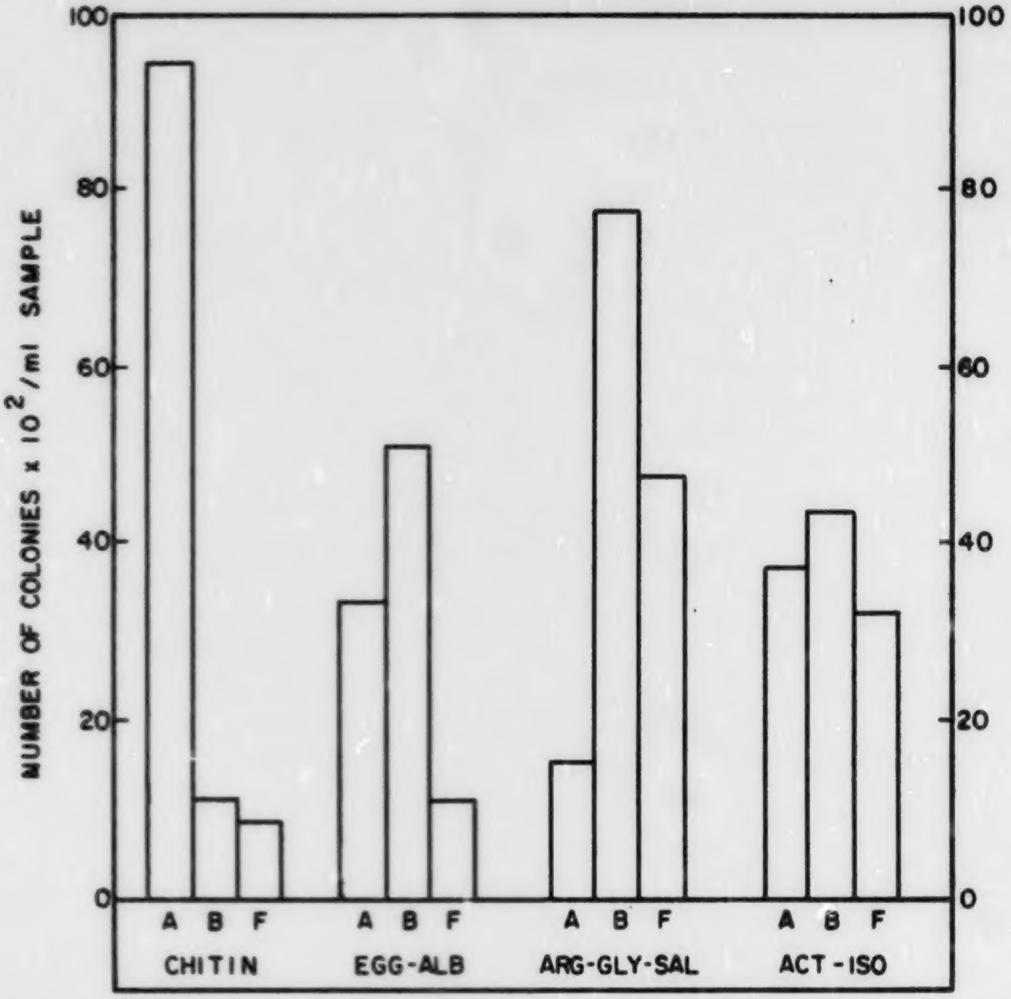


FIGURE 5. AVERAGE NUMBER OF COLONIES OF ACTINOMYCETES, A; BACTERIA, B; AND FUNGI, F, OBTAINED BY PLOTING 20 SAMPLES OF DILUTED GREEN BAY WATER ON CHITIN- MINERAL SALTS AGAR (CHITIN), EGG-ALBRIMIN AGAR (EGG-ALB), ARGININE - GLYCEROL SALTS AGAR (ARG-BLY-SAL), AND BACTO-ACTINOMYCETE ISOLATION AGAR (ACT ISO).

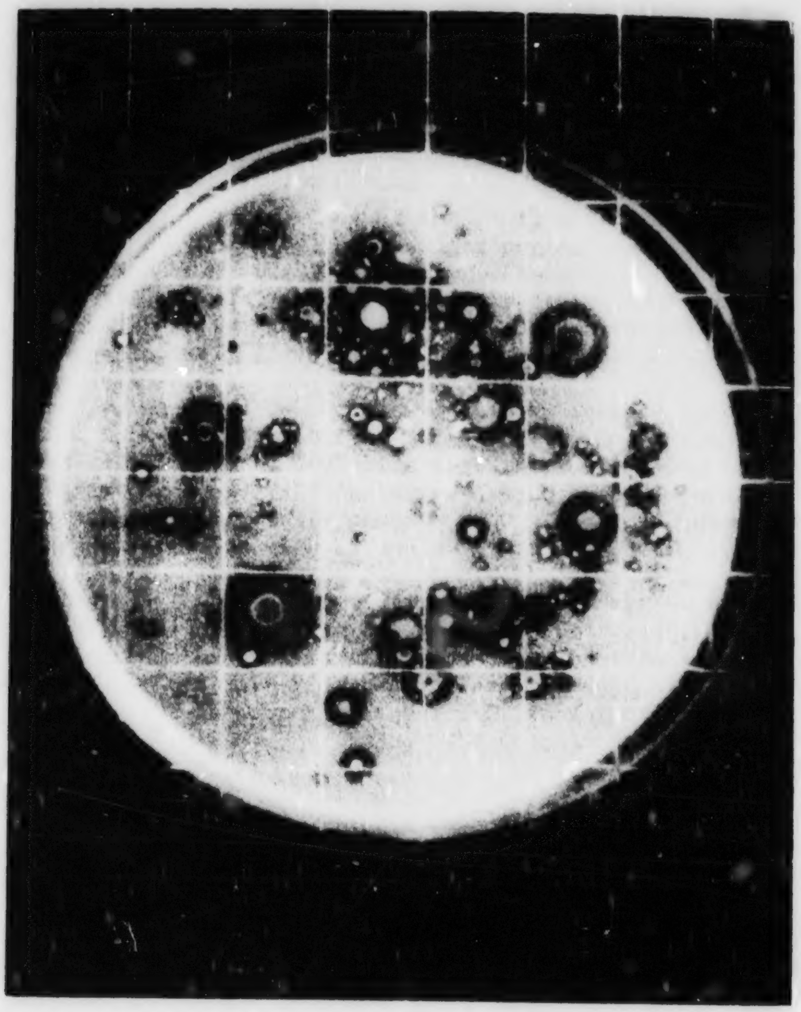


Figure 6. A chitin-mineral salts agar culture (14 days incubation) of a natural mixture of actinomycete organisms. While somewhat crowded, "clear zones" surrounding the actinomycete colonies are well defined in the translucent agar.

by gross morphology and manner of spore formation. An "other" category includes isolates which fell outside of these genera. The primary identifying factors in genera identification were: Streptomyces, readily apparent aerial hypha with long spore chains; Micromonospora, no aerial hypha with single round spores formed at sides of mycelium; Nocardia, microscopic aerial hypha with arthrospore formation. Most sporulation observations were done by optical microscopy. Figure 7 gives highly magnified examples of the various actinomycete genera obtained with an electron microscope.

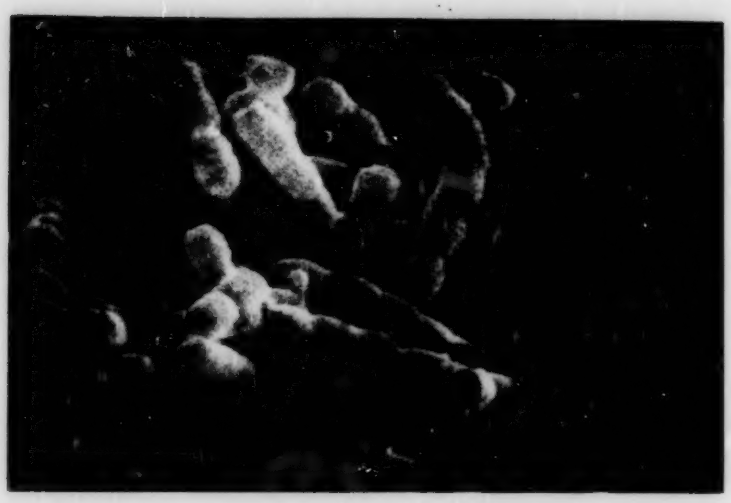
In an effort to obtain an estimate of species and/or strains present in northern Green Bay, several hundred isolates were grouped according to sometimes minor differences in growth morphology (i.e., shades of color and quality of growth) on arginine-glycerol salts agar. This original grouping was narrowed to about twenty different groups. An example of each group was chosen at random and further defined according to characteristics given in Table 1. By this delineation at least three genera and 12 different strains were present in northern Green Bay. Only a few strains were dominant in northern Green Bay. On the average, more than half the isolates examined from nearshore water samples belonged to Groups 1-4 (Table 1) and were identified as members of the Streptomyces genus. A particularly odoriferous Streptomyces isolate (E_{1a}) was used in many of the laboratory experiments. Further classification of the E_{1a} isolate suggests it is Streptomyces lavendulae as defined by the taxonomic approach of Shirling and Gotlieb, International Journal of Systematic Bacteriology, Vol. 18, p. 137 (1968).

Field Investigation

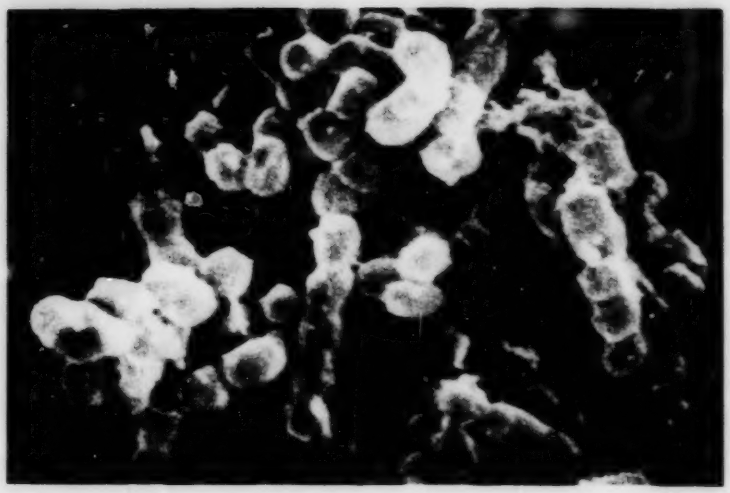
Actinomycete Distribution - Northern Green Bay

The actinomycete distribution in northern Green Bay is summarized in Table 2. Maximum numbers (Table 2) were found at the inner most marsh station (Pml) and at the three nearshore stations (Escanaba > Gladstone > Menominee). Minimum levels occurred at Little Bay de Noc, Upper Green Bay and Middle Green Bay (Menominee - offshore). Similarly, maximum concentrations in the bottom sediments occurred at the nearshore stations (Escanaba > Gladstone > Menominee). Concentrations in the sediments were always at least two orders of magnitude (10^4 versus 10^2) greater than water column levels. Inspection of water column data revealed that actinomycete concentrations did not vary with depth.

In addition to station differences in relative actinomycete numerical abundance, the population composition also varied. Figures 8 to 12 indicate the seasonal and station variation of the major taxa. Three actinomycete genera were always present; Streptomyces, Micromonospora and Nocardia. There existed a distinct difference among the stations. Streptomyces were the dominant component (>50 percent of the population) at the nearshore stations (Escanaba > Menominee > Gladstone) while



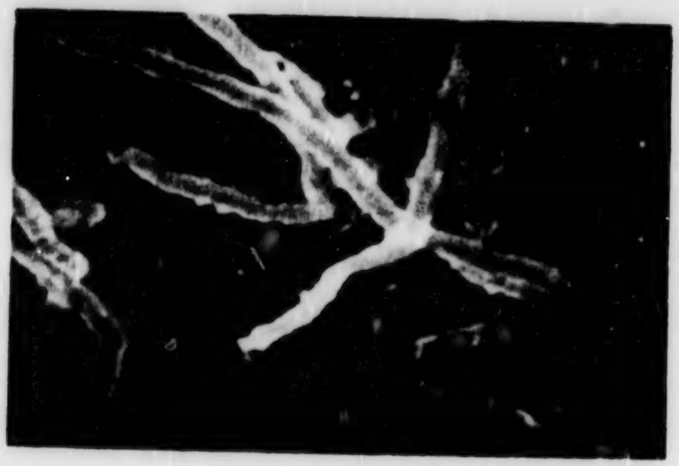
Streptomyces spore chains, isolate E_{1a}; (mag. 10,000x)



Streptomyces isolate T_{19}, note the apparent spine formation on spores absent for isolate E_{1a}; (mag. 10,000x)

Figure 7. Examples of mycelium and spore formation for some actinomycetes isolated from Green Bay.

Micromonospora showing spore formation at sides of mycelium; (mag. 20,000 x)



Nocardia, sporulation not apparent; (mag. 20,000x)

Probably Nocardia with apparent arthrospore formation; (mag. 10,000x)

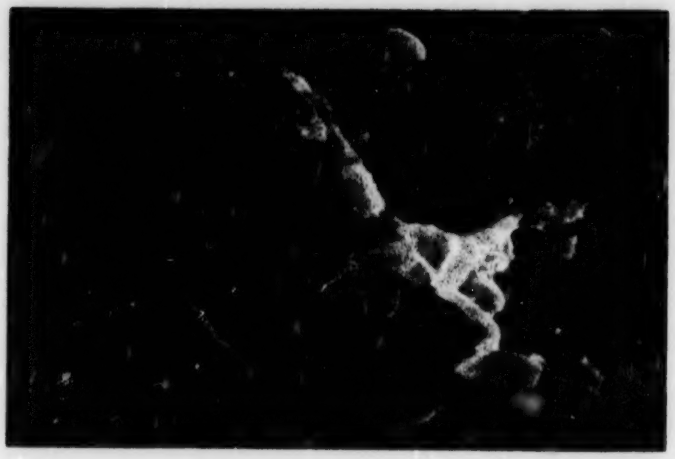


Figure 7. Continued.

Table 1. Identification of Actinomycetes Isolates.

Classification of Isolates	Growth[4]			Reverse Pigment Production			Colony, shape color			Odor	Spore
	A[1]	B[2]	C[3]	A	B	C	A	B	C		
Group 1	+	+++	++	no	Yellow	Yellow	no	Smooth Oily Green	Smooth White	Musty	Chain Round
Group 2	+	+++	++	no	Brown	no	no	Mosaic Fluffy White	Smooth White	Musty	Chain Round
Group 3	+	+++	++	no	Orange	no	no	Smooth White	Ball-like White	Musty	Chain Round
Group 4	+	+++	+	no	Brown	no	no	Ball-like White	no	Musty	Chain Round
Group 5	++	+++	++	Green	Brown	Brown	Fluffy Green	Ball-like Pink	Ball-like Pink	Strong Musty	Undetermined Single
Group 6	++	+++	+	no	Green	Green	Smooth White	Ball-like Green	Ball-like Green	Strong Musty	Chain Round
Group 7	+	+	+	no	no	no	no	Smooth White	no	no	Undetermined
Group 8	+	+++	-	no	Brown	no	no	Ball-like White	no	Sweet	Single Round
Group 9	++	+++	+	Brown	Black	Gray	Smooth White	Smooth Brown	Smooth White	Sweet	Undetermined
Group 10	+	++	++	no	Black	Gray	no	Ball-like Brown	Smooth White	no	Chain Rod
Group 11	-	+	-	no	no	no	no	no	no	no	Rod
Group 12	-	+	+	no	Brown	no	no	Smooth Pink spot	no	no	Undetermined Round

[1] Czapeck's agar. [2] Yeast extract agar. [3] Starch agar. [4] - = no growth ++ = fair growth
+ = poor growth +++ = good growth

Table 2. Actinomycete numerical abundance and Streptomyces percentage of population in water ans sediments of northern Green Bay.

Station	Actinomycetes [a] mean counts/ml Water	Actinomycetes [a] mean counts/ml Sediment ($x10^4$)	Percent Streptomyces Water	Percent Streptomyces Sediment
Big Bay de Noc	3	0.2	21	37
Upper Green Bay	3	1.1	30	27
Middle Green Bay (Menominee-offshore)	8	0.3	28	26
Escanaba	294	81.2	74	71
Gladstone	62	23.7	51	68
Menominee-nearshore	39	4.1	63	39
Portage Marsh #1	327	6.1	55	75
Portage Marsh #2	70	20.2	53	75

[a] Mean of four surveys (April - October, 1974).

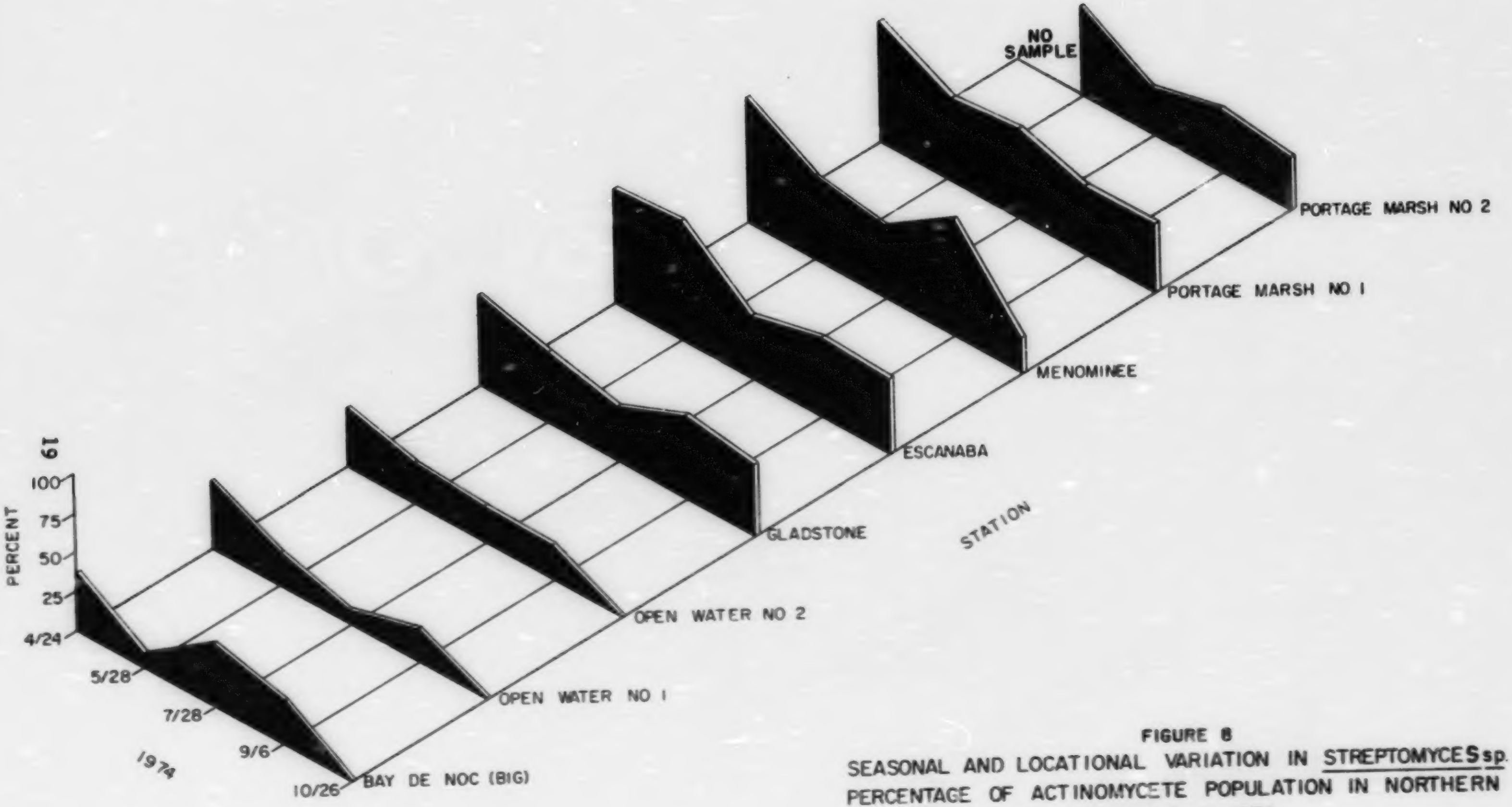


FIGURE 8

SEASONAL AND LOCATIONAL VARIATION IN STREPTOMYCES sp. PERCENTAGE OF ACTINOMYCETE POPULATION IN NORTHERN GREEN BAY (LAKE MICHIGAN) IN 1974.

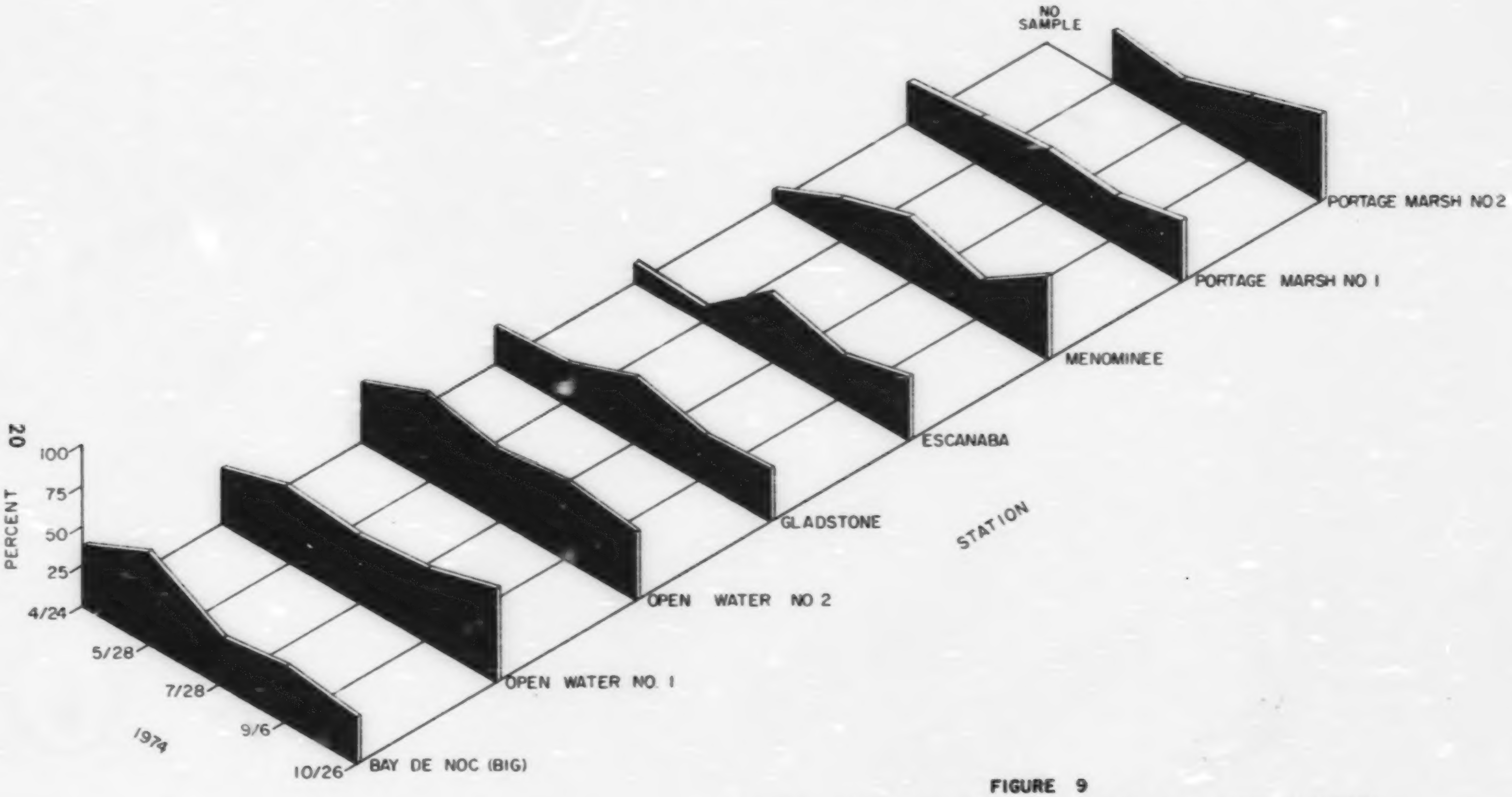


FIGURE 9

SEASONAL AND LOCATIONAL VARIATION IN MICROMONOSPORA sp. PERCENTAGE OF ACTINOMYCETE POPULATION IN NORTHERN GREEN BAY (LAKE MICHIGAN) IN 1974.

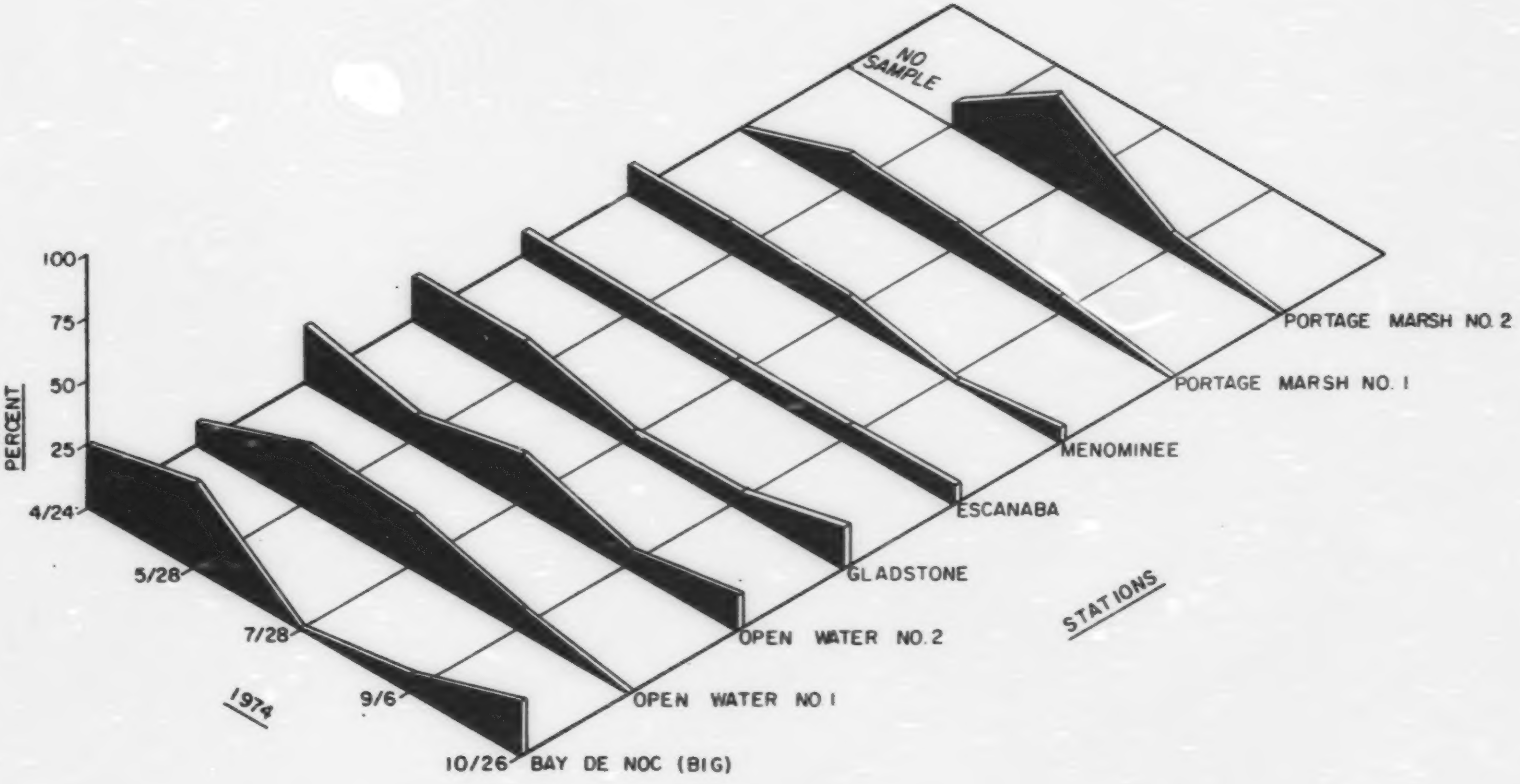


FIGURE 10

SEASONAL AND LOCATIONAL VARIATION IN NOCARDIA sp PERCENTAGE OF ACTINOMYCETE POPULATION IN NORTHERN GREEN BAY (LAKE MICHIGAN) IN 1974.

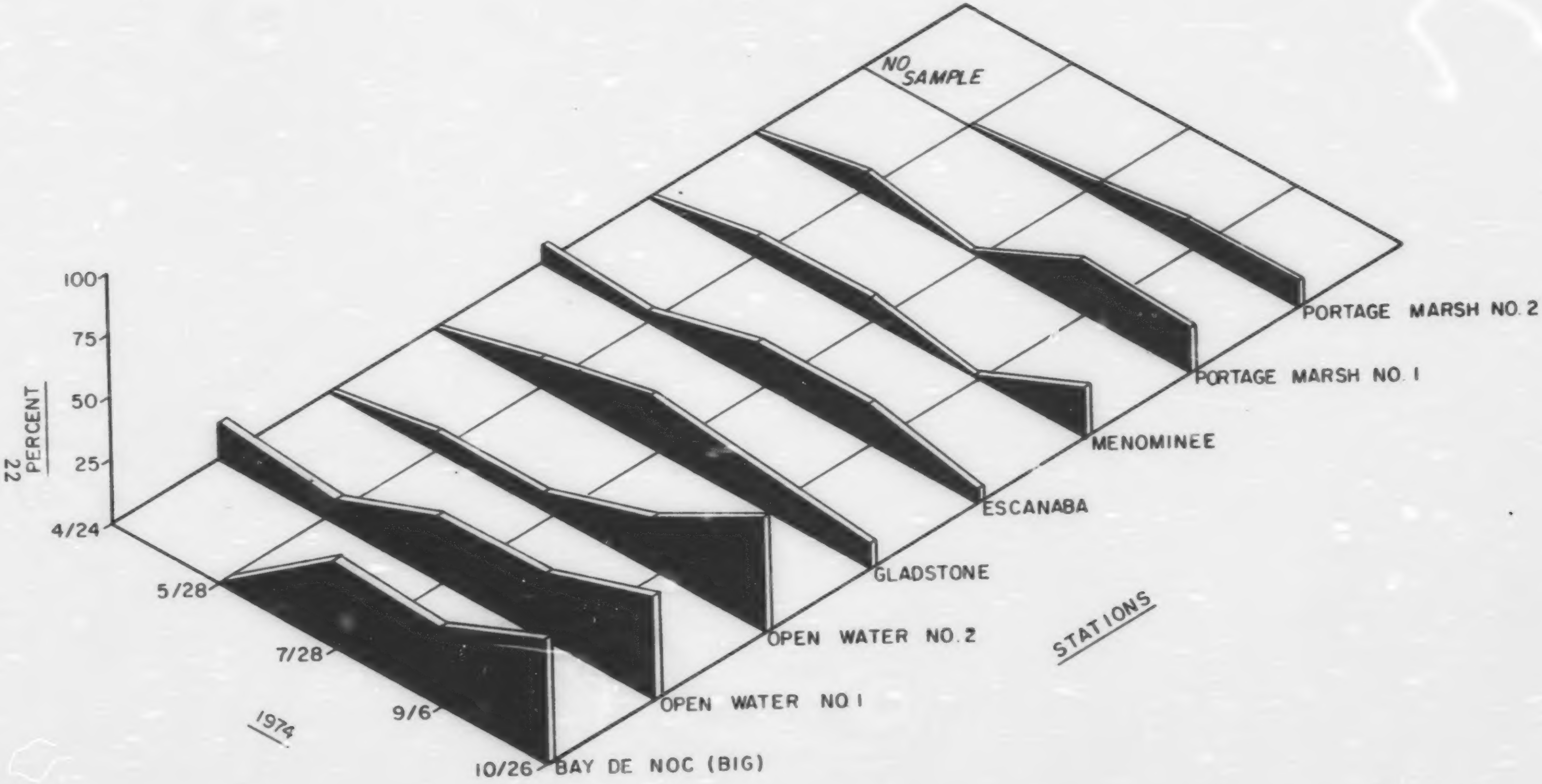


FIGURE 11

SEASONAL AND LOCATIONAL VARIATION IN UNIDENTIFIED ACTINOMYCETES IN NORTHERN GREEN BAY (LAKE MICHIGAN) IN 1974.

Micromonospora were predominant in the open water stations; Big Bay de Noc, Upper Green Bay (OW1) and Middle Green Bay (OW2). Nocardia were present, but never comprised more than 25 percent of the population at nearshore or offshore Green Bay stations.

The two marsh stations were dominated by Streptomyces and also had high standing crops of actinomycetes similar to the nearshore stations. In light of the abundant submerged and emergent aquatic vegetation contained in a marsh, it is understandable that these decomposer organisms were rather abundant.

The numerical and genera differences in the actinomycete population do not correlate with threshold odor number (TON) concentrations throughout Northern Green Bay (Figure 12). Average TON levels never exceeded 2.5 units. Compared to values (Figure 1) observed at Escanaba during periods of intense earthy-musty odor in 1972, these represent background levels and are not sufficiently intense to require special treatment at the water purification facilities.

Actinomycete Distribution - Great Lakes

Actinomycete distribution in the nearshore waters of the Great Lakes contiguous to Michigan are summarized in Table 3. Fourteen of the twenty-six water purification plants had previously experienced earthy-musty odor problems.

The over-all results must be interpreted with some caution, since the data base is relatively small. Furthermore, there were no odor outbreaks in these areas during the three sampling periods. However, a general trend is evident. Figure 13 shows the relative difference in actinomycete abundance between locations with a history of earthy-musty odor occurrences and those with no history of this odor. The actinomycete counts decreased dramatically between the April and August surveys at most locations (Figure 13 and Table 3) and increased again in October. The reason for the sharp decrease and subsequent increase is not known. In spite of this unexplained decrease, further statistical analysis (Tukey's w-procedure) indicated a significant difference ($p < 0.05$) in actinomycete abundance between locations and dates (Steel and Torrie, 1960). The twenty-six communities were divided into two significantly ($p < 0.05$) distinct groups; those with a low and high number of actinomycetes in the raw water supply. This information was compared with data on the past occurrence of earthy-musty odors at each water purification plant (Table 4).

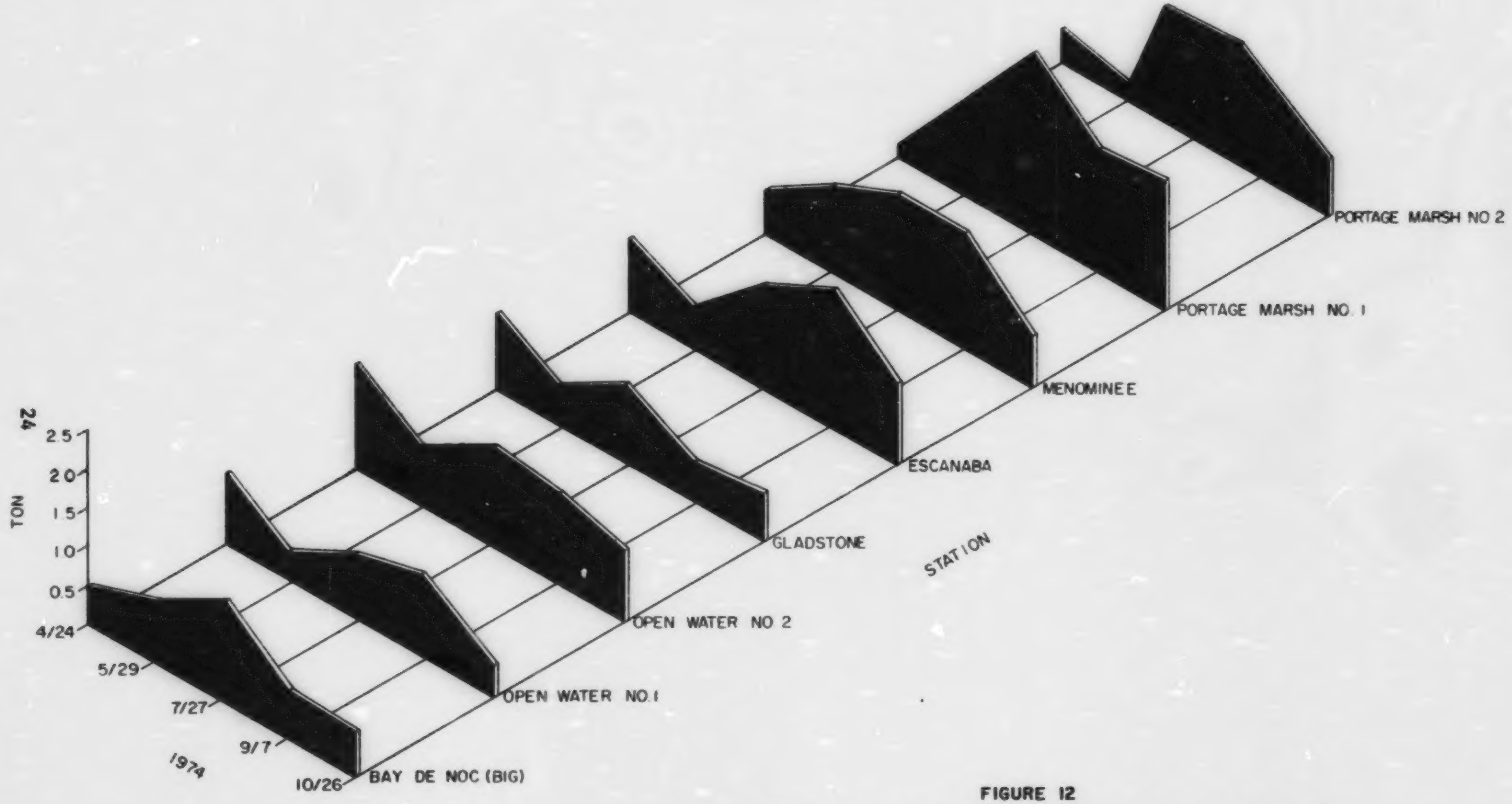


FIGURE 12

SEASONAL AND LOCATIONAL DISTRIBUTION OF THRESHOLD ODOR NUMBER (TON) IN NORTHERN GREEN BAY (LAKE MICHIGAN) IN 1974.

Table 3. Mean number of actinomycetes (counts/ml) in raw water supply of twenty-six (26) Great Lakes municipal water treatment facilities.

City	Location	1974		
		April 29	August 19	October 14
Traverse City	Grand Traverse Bay	0.0	0.7± 1.2	0.0± 0.0
St. Ignace	L. Huron	0.0	2.7± 0.6	6.7± 0.6
Port Huron	L. Huron	2.0± 2.6	*	3.0± 2.0
Saginaw	Saginaw Bay	2.3± 2.3	16.0± 5.3	3.3± 0.6
Marquette	L. Superior	3.3± 1.5	1.7± 1.5	6.3± 3.1
St. Clair	St. Clair River	5.0± 4.6	1.3± 1.5	113.0± 9.5
Sault Ste. Marie	L. Superior	11.7± 1.5	0.3± 0.6	4.7± 0.6
Grosse Pte. Farms	L. St. Clair	13.0± 6.1	9.0± 4.6	4.0± 2.6
South Haven	L. Michigan	13.3± 2.5	0.3± 0.6	47.0± 1.0
East Tawas	L. Huron	19.0± 3.6	1.7± 0.6	5.7± 2.1
Detroit	Detroit River	20.3± 7.8	*	125.0±15.1
Copper Harbor	L. Superior	23.3± 0.6	*	*
Ludington	L. Michigan	29.0±22.6	0.3± 0.6	1.0± 1.0
Menominee	Green Bay	35.0± 3.6	6.3± 2.5	121.0± 9.6
White Pine	L. Superior	36.0± 7.2	0.0	8.3± 3.1
Holland	L. Michigan	41.7± 5.1	1.7± 0.6	3.7± 3.1
Escanaba	Green Bay	42.3± 0.6	*	49.7±16.2
Pinconning	Saginaw Bay	49.3±44.8	6.3± 4.5	36.7±17.6
Harbor Beach	L. Huron	59.0±28.8	6.7± 8.9	10.0± 1.7
Benton Harbor	L. Michigan	65.0±30.4	3.0± 0.0	38.7± 5.1
Grand Rapids	L. Michigan	66.0± 7.0	1.6± 0.5	12.7± 1.2
Bay City	Saginaw Bay	72.7±26.0	*	57.3±13.6
Alpena	Thunder Bay	73.3±15.7	3.0± 1.0	3.3± 0.6
Mt. Clemens	L. St. Clair	91.3± 8.5	24.3± 2.3	14.3± 4.5
Muskegon	L. Michigan	96.7±11.4	1.7± 0.6	71.0± 2.6
Monroe	L. Erie	97.0± 7.0	16.7± 1.5	7.7± 1.2

* Samples lost.

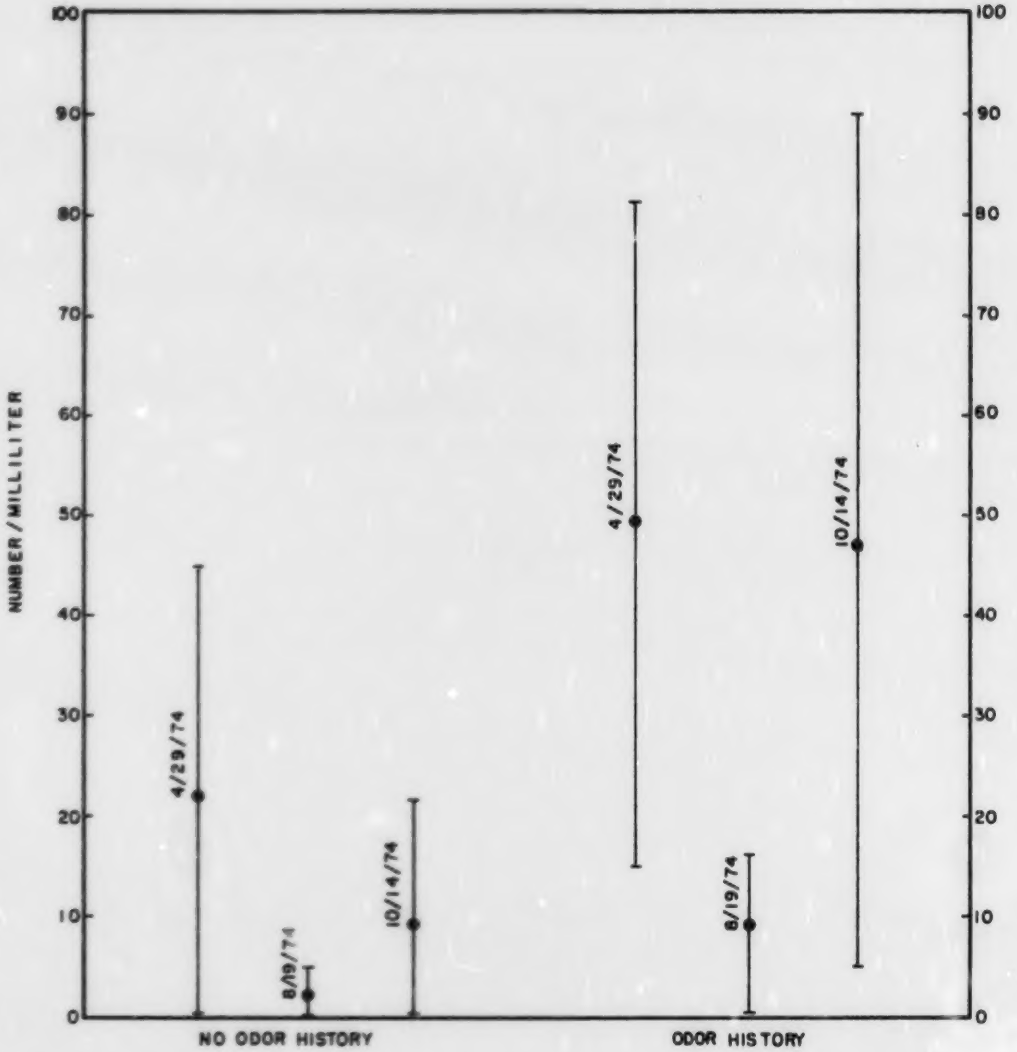


FIGURE 13. ABUNDANCE OF ACTINOMYCETES IN RAW WATER SUPPLY OF TWENTY SIX MICHIGAN MUNICIPALITIES THAT USE THE GREAT LAKES. FOURTEEN HAVE A HISTORY OF EARTHY - MUSTY ODOR OCCURRENCE. MEAN ± 1 STANDARD DEVIATION IS GIVEN FOR THREE SURVEY DATES IN 1974.

Table 4. Actinomycete abundance in statistically significant ($p > 0.05$) groups (high versus low abundance) and percent of communities in each group with a history of earthy-musty odor problems.

Survey 1974	(Number/ml)	Percent of communities with a history of odor problems
April	>19	65
	≤19	33
August	> 1.7	67
	≤ 1.7	14
October	>43	89
	≤43	38

The mean total actinomycete count/ml and percent of *Streptomyces* of the standing crop for the water supplies is shown in Figure 14. It depicts the probable dependence of odor occurrence on the average actinomycete population size and percent of *Streptomyces* in those populations. Locations not reporting odor problems (clear circles) are clearly separated from those that do (shaded circles) by the horizontal dashed line. *Streptomyces* comprise 28 percent or more of the actinomycete standing crop for all WWTP with a known (one or more occurrence) taste and odor problem. Also, as total actinomycete population size increased, the number of locations with an odor problem are more prevalent. Another point of ecological importance is indicated here. *Streptomyces* genera comprise a larger percent of the actinomycete population at the higher standing crops. The *Streptomyces* organisms are considered primarily responsible for the synthesis of odor compounds and apparently must be a large enough fraction of the population to produce objectionable quantities of the odor causing compounds.

Further analysis of the 21 communities participating in all three surveys also supports the conclusion that actinomycete counts are generally higher at locations with a history of earthy-musty odors than those without the odor history. They were ranked from lowest to highest based on numerical abundance of actinomycetes and then assigned corresponding numerical values (Table 5). The assigned numerical values were then summed for the three surveys and the communities ranked according to these sums. None of the seven (0 percent) communities with the lowest rankings had ever experienced earthy-musty odors. However, five of the next seven (71 percent) communities with intermediate rankings and six of the seven (86 percent) communities with the highest rankings had a history of earthy-musty odor.

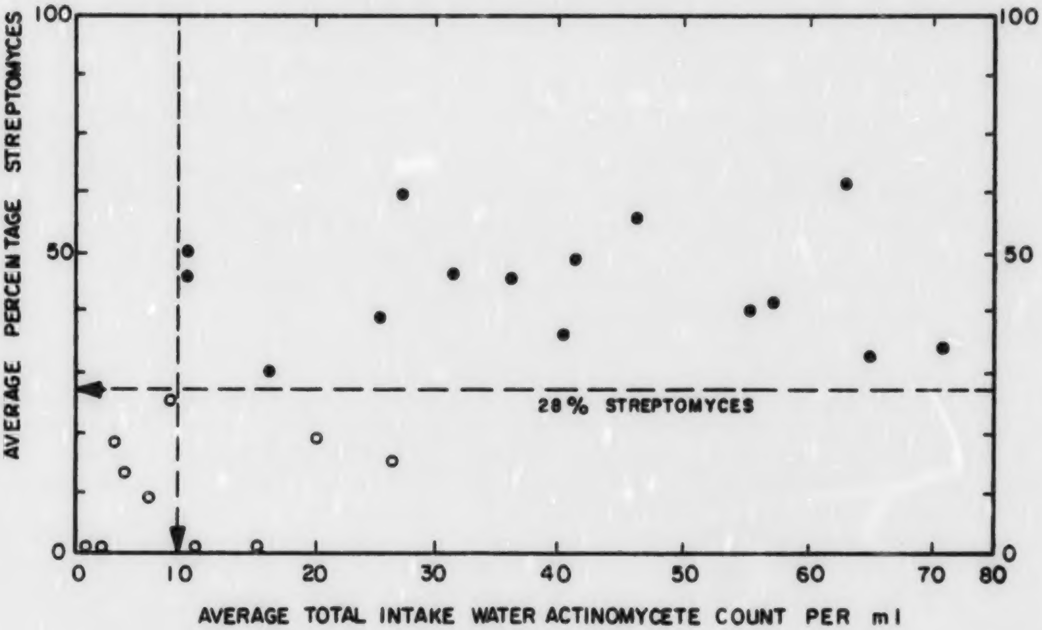


FIGURE 14. PLOT OF AVERAGE TOTAL ACTINOMYCETE COUNTS AND PERCENTAGES OF STREPTOMYCES FOR VARIOUS WATER INTAKE SAMPLES. ONLY DATA POINTS WHERE EARTHY-MUSTY-GRASSY ODORS HAVE BEEN REPORTED ARE SHADED.

Table 5. Ranking of Great Lakes municipal raw water supplies by relative actinomycete abundance (1974).

Community	Individual survey rankings			Sum of rankings
	April 29	August 19	October 14	
Traverse City	1	5	1	7
Sault Ste. Marie	6	2	7	14
Ludington	10	4	2	16
Marquette	4	9	9	22
St. Ignace	2	12	10	24
White Pine	12	1	12	25
East Tawas	9	8	8	25
Saginaw*	3	19	3	25
South Haven	8	3	18	29
Holland*	13	11	5	29
Grosse Pte. Farms*	7	18	6	31
St. Clair*	5	6	20	31
Alpena	18	14	4	36
Grand Rapids*	17	7	14	38
Harbor Beach	15	17	13	45
Benton Harbor*	11	15	21	46
Menominee*	16	13	17	47
Pinconning*	14	16	16	46
Muskegon*	20	10	19	49
Monroe*	21	20	11	52
Mt. Clemens*	19	21	15	55

*Have experienced earthy-musty odors.

Frequency distribution of the genera Streptomyces, Micromonospora and Nocardia was also determined for the August and October dates. Generally, Streptomyces were more abundant for both surveys in raw water supplies of communities with a history of earthy-musty odor occurrences. The mean percentage of Streptomyces in the actinomycete population was more than twice as high at locations which have reported earthy-musty odor problems than those that reported no history of such problems (Figure 15).

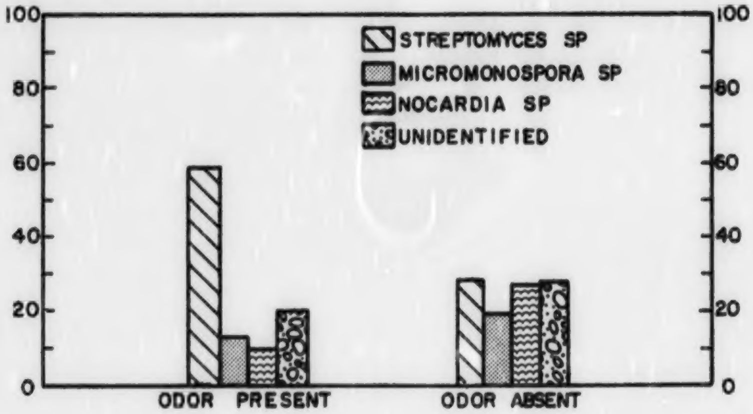


Figure 15. Distribution of actinomycete genera in raw water of eleven (11) Michigan municipal water supplies with a history of earthy-musty odor problems and eleven (11) without this odor present. The Great Lakes are the water source.

Great Lakes Eutrophication - Actinomycete Relationship

In addition to assessing the actinomycete numerical abundance and population structure in the nearshore waters of the Great Lakes, the relationship between eutrophication of the Great Lakes and odor occurence history was examined. Water samples were collected from fourteen municipal water purification plants (Figure 3) and analyzed for total organic carbon and chlorophyll a content.

Total organic carbon concentrations ranged from 1.4 to 5.0 mg/l while chlorophyll a concentrations ranged from 2.0 to 39.7 mg/l (Table 6). Using total organic carbon and chlorophyll a as indicators of the relative eutrophy among the stations, there is an apparent pattern; namely, locations with a history of earthy-musty odors are also the sites which had higher concentrations of TOC and chlorophyll a.

Table 6. Total organic carbon and chlorophyll a concentrations in raw water supply of fourteen Michigan water purification plants collected June 6, 1974.

Location	Total Organic Carbon (mg/1)	Chlorophyll a (μg/1)
Munising	1.4	-
St. Ignace	1.6	-
Sault Ste. Marie	1.8	2.2
Port Huron	1.9	-
Grand Rapids*	2.0	3.5
Ludington	2.4	2.0
Benton Harbor	2.5	5.0
Mt. Clemens*	3.1	21.9
Escanaba*	3.6	22.0
Menominee*	3.8	16.7
Alpena	3.9	10.0
Gladstone*	4.6	13.0
Monroe*	4.8	38.5
Bay City*	5.0	39.7

*History of taste and odor occurrence.

Six replicate raw water samples from each of the 14 locations were inoculated with 1 ml of isolate E_{1a} inoculum and incubated for 14 days (24-28°C). Inocula of different spore densities were used and the resulting cultures were designated as Group A or B depending on the inoculum used. Water from the City of Lansing, Michigan was used as a control because it was ground water and readily available.

Growth in the culture was defined by use of a "growth factor" which was determined by dividing the final 14-day plate counts by the initial plate counts (Table 7). Growth was generally significantly greater for both groups in locations having a history of odor problems than in locations never reporting odor problems (statistical test using analysis of variance and Ducan's Multiple Range Test). St. Ignace (Group A) was the sole exception to the above statement. There has been no odor problem there, but actinomycete growth in water from St. Ignace was significantly greater than in Munising and Sault Ste. Marie water in which there also were no odor problems.

Table 7. Growth factors for actinomycetes cultured in raw water from 14 Great Lakes municipal water purification plants.

Inoculum Group	Location	History of earthy-musty odor problems	Growth factor
A	Munising	no	3.4
	Sault Ste. Marie	no	4.1
	St. Ignace	no	16.8
	Gladstone	yes	17.2
	Escanaba	yes	20.8
	Menominee	yes	24.6
B	Ludington	no	0.3
	Port Huron	no	0.3
	Alpena	no	1.0
	Bay City	yes	7.5
	Benton Harbor	yes	11.0
	Grand Rapids	yes	13.7
	Monroe	yes	27.6
	Mount Clemens	yes	31.6

To demonstrate the apparent relationship between enrichment of waters (i.e., high total organic carbon concentrations), actinomycetes and past odor occurrences, rankings were developed for total organic carbon, field actinomycete counts and laboratory actinomycete growth data. Each of the 13 locations having data for all the parameters were assigned a numerical value (1-13) for each parameter from lowest to highest (Table 8).

Table 8. Ranks of total organic carbon, laboratory actinomycete and field actionmycete abundance from raw water of thirteen Michigan municipal water purification facilities (June, 1974) on Great Lakes.

City	Total organic carbon	Rank field actinomycete counts	Laboratory actinomycete growth	Total
Port Huron	4	2	1	7
Munising	1	3	4	8
Sault Ste. Marie	3	4	5	12
St. Ignace	2	1	9	12
Ludington	6	5	2	13
Benton Harbor*	7	8	7	22
Grand Rapids*	5	9	9	22
Alpena	11	11	3	25
Escanaba*	9	7	10	26
Menominee*	10	6	11	27
Bay City*	13	10	6	29
Mount Clemens*	8	12	13	33
Monroe*	12	13	12	37

* History of earthy-musty odors.

The five communities with the lowest total ranking have never experienced earthy-musty odor problems. Alpena was the only one of the eight highest ranking which did not have a history of earthy-musty odor occurrence. Communities with the highest rankings also experienced the most severe odor problems. For example, Benton Harbor has experienced only occasional odor problems and Grand Rapids had one odor outbreak in 1972. Escanaba and Menominee had severe odor problems intermittently every fall and winter since 1970. Though the odor has subsided somewhat in recent years, Bay City has experienced continuous problems since the 1950's and Monroe had odor outbreaks several times each year for a number of years.

Algal Investigations

In assessing the biologic source of the earthy-musty odor in northern Green Bay, the blue-green fraction of the phytoplankton population was screened (Appendix E) and compared to odor producing species as reported in the literature. Many blue-green algae capable of producing earthy-musty odor compounds are in the *Oscillatoria* genus. Only two species of *Oscillatoria* were rather abundant in northern Green Bay during July; *Oscillatoria retzii* was the dominant component in samples from middle Green Bay and *Oscillatoria limnetica* was occasionally present. *Oscillatoria tenus* or *Oscillatoria chalybea* have been identified as the principal causative agent of earthy-musty odor in reservoirs (Aschner et al., 1968; Leventer and Eren, 1970). Neither of these were found.

Inasmuch as *O. retzii* is a benthic alga and is only facultatively planktonic (Stoermer, personal communication, 1974), its presence in our epilimnion samples is suggestive of the presence of a benthic algal community. Stoermer (personal communication, 1974) indicates benthic algal mats are present in northern Green Bay. Through the use of SCUBA techniques, a qualitative survey of the benthos was conducted in June (1974). Little benthic algal growth was observed and no blue-green taxa were identified.

Laboratory Investigations

Over the past fifty years the laboratory work on actinomycete and odor-production in natural water is realtively meager. Only a handful of researchers have devoted effort to this field in contrast to the pharmaceutically related actinomycete research. Over 50 chemical compounds and antibiotics (e.g., Tetracycline, Actinomycin, Streptomycin) with practical applications have been isolated from actionmycetes. There has been a great deal of speculation, but little data is available from carefully controlled experiments or field surveys on the ecology of actinomycetes. Our laboratory investigations were designed to determine the response of actinomycetes to concentrations of certain organic materials commonly discharged to Green Bay. The primary objectives were to relate the experimental responses under controlled conditions to theoretical responses based on conditions present in Green Bay and to determine if such responses could theoretically cause odor problems in Green Bay. Specific phases of the laboratory experiments included:

1. Actinomycete Energy (Carbon) Sources.
   a. Phenol - Cellulose
   b. Municipal-Industrial effluent
   c. Algal Assemblages
2. Relationship between earthy-musty odor production and actinomycetes growth.

Phenol - Cellulose

Inputs of phenol and cellulose to Green Bay originate from the biodegradation of wood materials of natural origin and pulp mill effluents. Simple phenol and washed paper fiber were chosen as models for the complex natural products. Reagent grade phenol and a suspension of Whatman #1 filter paper prepared in a Waring blender were used with distilled water to prepare culture mediums. Phenol or paper fiber concentrations were adjusted from 0.1 to 10,000 mg/l. Similar cultures were also prepared with the addition of mineral salts at concentrations approximating those of the chitin agar. The pH of all cultures was adjusted to 8.0 using sodium hydroxide. Aliquots of a spore suspension of Isolate E_{1a} were added, an initial count was determined, and then plate counts were again done after 14 days incubation at both 10 and 25°C.

Neither type of material promotes extensive growth (Table 9). However, the presence of the mineral salts promotes limited utilization of both phenol and cellulose and growth factor trends indicate the higher salts concentrations also inhibit growth. When phenol and cellulose showed growth stimulation, a concentration of 0.1 ppm was not growth limiting. The 10,000 mg/l concentrations appeared to destroy the spores. This may be indirectly related to high sodium concentrations required to bring the cellulose cultures to a pH of 8.0 and not the organic compounds. It is evident, however, that actinomycetes can utilize phenol and cellulose as energy sources under certain conditions.

Municipal - Industrial Effluents

Laboratory study on the growth and odor production of actinomycete isolates from waters of northern Green Bay indicate the ability of these organisms to utilize constituents in typical municipal and industrial (paper processing plants) effluent. Six actinomycete isolates were inoculated into various dilutions of final effluents from a wastewater treatment (secondary) plant and a paper mill treatment plant. In a series of duplicate experiments all the isolates except T_2 achieved substantial growth in the paper mill effluent (Table 10). All isoaltes except T_5 and PM-1 had greater growth response with both energy sources than the control culture (Table 10). Since growth was less than the control, the constituents of the WWTP effluent were apparently inhibitory to the growth of these two isolates.

To further assess the effect of these effluents on actinomycete growth, two isolates (E_1 and T_5) were inoculated into a series of dilutions for each effluent. T_5 isolate, in contrast to inhibition in 100% effluent levels (Table 10) grew in the dilute concentrations of both effluents (Table 11). However, its maximum growth response in 5% effluent was much less in WWTP media (only 4-fold increase) than in paper mill media (11-fold increase). Over-all, T_5 isolate grew less successfully at all dilutions than did E_1 isolate. Maximum growth response for the latter was 19-fold in paper mill effluent (5% effluent). Growth by both isolates was greatest at the lower effluent concentrations and progressively decreased with increasing effluent concentration.

Table 9. Growth of Isolate E_{1a} in phenol and cellulose cultures.

Nutrient	Nutrient Conc. (mg/l)	Average Growth Factor	Corrected Growth Factor
Phenol (10°C)	0	1.28	-
	0.1	1.30	1.01
	1	1.23	0.96
	10	1.20	0.93
	100	1.17	0.91
	1000	1.16	0.90
	10,000	0	0
Phenol (25°C)	0	1.46	-
	0.1	1.36	0.93
	1	1.30	0.89
	10	1.30	0.89
	100	1.18	0.80
	1000	1.11	0.76
	10,000	0	0
Phenol plus Mineral salts (10°C)	0	2.18	-
	0.1	4.08	1.87
	1	3.17	1.45
	10	3.06	1.40
	100	3.07	1.40
	1000	2.31	1.05
	10,000	0	0
Phenol plus Mineral salts (25°C)	0	18.50	-
	0.1	65.26	3.52
	1	37.92	2.05
	10	34.06	1.84
	100	32.69	1.76
	1000	23.54	1.27
	10,000	0	0
Cellulose (10°C)	0	1.16	-
	0.1	1.19	1.02
	1	1.23	1.06
	10	1.19	1.02
	100	1.17	1.00
	1000	1.14	0.98
	10,000	1.11	0.95

Table 9. Continued.

Nutrient	Nutrient Conc. (mg/l)	Average Growth Factor	Corrected Growth Factor
Cellulose (25°C)	0	12.17	-
	0.1	13.99	1.14
	1	13.23	1.08
	10	12.82	1.05
	100	12.13	0.99
	1000	11.97	0.96
	10,000	11.77	0.96
Cellulose plus Mineral salts (10°C)	0	1.94	-
	0.1	3.78	1.94
	1	2.88	1.48
	10	2.28	1.17
	100	2.50	1.28
	1000	2.05	1.05
	10,000	1.92	0.98
Cellulose plus Mineral salts (25°C)	0	18.00	-
	0.1	64.72	3.59
	1	51.31	2.85
	10	43.45	2.41
	100	28.81	1.60
	1000	26.29	1.46
	10,000	24.37	1.35

Table 10. Effect of 100 percent paper mill and municipal wastewater (secondary) effluent on actinomycete isolate growth.

Isolates	Initial Count	14-day Culture (counts per ml) Paper Mill Effluent	Municipal WWTP Effluent	Tap Water (control)
E_1	2.2×10^3	6.9×10^9	9.3×10^7	2.0×10^7
T_2	1.7×10^4	3.2×10^4	2.2×10^5	1.3×10^4
T_3-1	8	9.3×10^2	5.1×10^2	2.7×10^2
T_5	1.6×10^3	1.2×10^4	1.0×10^2	3.7×10^3
T_{19}	7.9×10^2	9.9×10^4	3.9×10^4	1.6×10^4
PM_1	7.6×10^8	7.6×10^8	3.8×10^4	1.4×10^7

Table 11. Actinomycete isolates (E_1 and T_5) growth (counts/ml) in dilutions of municipal waste water (secondary) and paper mill effluent.

Isolate	Time (days)	Control	Percent Effluent						
			5	10	20	40	60	80	100
					Paper Mill				
E_1	0	386[1]							
	7	425	964	750	780	458	506	338	589
	14	405	7800	6400	6000	4200	4100	3800	3900
T_5	0	18[1]	139	214	186	89	46	24	38
	7	34	632	601	483	78	64	89	82
	14	56							
						Municipal waste water			
E_1	0	386							
	7	425	633	609	488	428	456	484	529
	14	405	4300	4000	3200	1000	800	900	600
T_5	0	18							
	7	34	88	93	74	38	41	23	32
	14	56	212	186	131	42	50	41	21

[1] Initial isolate inoculum the same for all experimental dilutions.

Of the six isolates screened in the above-mentioned experiments, only E_1 (Streptomyces sp.) had an earthy-musty odor noted with its growth. The intensity of the odor (Threshold Odor Number) was assessed on the 14 day cultures. The results of Isolate E_1 are in Table 12.

Table 12. Comparison of 14-day growth factors with threshold odor numbers (TON) for autoclaved waste effluent cultures of Isolate E_1.

Nutrient Source	14-day growth factor at (24-28°C)	TON
1. Sterilized treated wastewater effluent (municipal) (100%)	4.3×10^4	627
2. Sterilized paper mill effluent waste (100%)	320×10^4	1032
3. Sterilized Lansing tap water	0.9×10^4	71
4. Unsterilized (1) above	3.3×10^4	275
5. Unsterilized (2) above	0.8×10^4	126
6. Unsterilized (3) above	0.5×10^4	43

The TON values roughly parallel the 14-day growth factors. However, there is no obvious mathematical relationship. There was an unusual amount of growth in the control culture. This contamination was due to the accidental introduction of nutrient media during inoculation.

The municipal and industrial effluents assessed are typical examples of conventionally treated organic inputs into Green Bay. The potential annual input from municipal wastewater treatment plants is indicated in Table 13. As of 1973, the discharge of 27 WWTP enter tributaries of the bay and two (Escanaba and Gladstone) enter Green Bay (Little Bay de Noc) directly. The major industrial activity on the watershed is paper manufacturing. Table 14 indicates their potential annual input to Green Bay. Together, these activities contribute over 122 million pounds of BOD and over 67 million pounds of suspended solids annually. The vast majority of these wastes enter the southern portion of Green Bay.

Table 13. Inputs to Green Bay from Municipal waste water treatment plants (1974).

State	Municipality	Primary receiving water	Treatment level	Mean discharge (MGD)	BOD^5 (lb./day)	Suspended solids (lb./day)
Mich.[1]	Escanaba	Little Bay de Noc	Secondary	1.60	146.4	159.7
	Gladstone	Little Bay de Noc	Secondary	0.75	124.8	124.8
	Forsyth Twp.	Escanaba River	Lagoons	0.25	35.4	72.8
	Caspian	Iron River	Primary	0.20	582.4	499.2
	Stambaugh	Iron River	Secondary	0.14	16.3	23.3
	Iron River	Iron River	Primary	0.48	335.5	235.6
	Iron Mtn.-Kingford	Menominee River	Primary	1.85	2,385.8	862.0
	Menominee	Menominee River	Secondary	2.68	445.0	445.0
	Norway	Menominee River	Secondary	0.35	29.1	55.3
	Powers	Cedar River	Lagoons	0.10	12.5	33.3
	Stephenson	Little Cedar River	Secondary	0.14	64.1	34.9
Wisc.[2]	Marinette	Menominee River	Primary	3.762	327	547
	Peshtigo	Peshtigo River	Secondary	0.487	138	84
	Oconto Falls	Oconto River	Secondary	0.239	61	57
	Gillett	Oconto River	Secondary	0.182	44	29
	Oconto	Oconto River	Secondary	1.446	126	266
	Green Bay	Fox River	Secondary	20.910	19,600	13,708
	Green Bay (Raw bypass)	Fox River	None	4.170	8,461	7,068
	Depere	Fox River	Secondary	2.652	1,076	1,032
	Depere (Raw bypass)	Fox River	None	1.125	2,452	2,038
	Wrightstown	Fox River	Secondary	0.170	56	55
	Kaukauna	Fox River	Secondary	1.953	245	388
	Little Chute	Fox River	Secondary	0.812	164	-
	Kimberly	Fox River	Secondary	0.544	196	92
	Appleton	Fox River	Secondary	14.020	4,612	6,181
	Appleton (bypass)	Fox River	Primary	2.040	3,540	1,920
	Menasha, West Plant	Fox River	Secondary	0.741	33	9
	Menasha, East Plant	Fox River	Secondary	0.618	79	92
	Neenah-Menasha	Fox River	Secondary	14.960	4,097	14,116
	Total			79.461	49,484.3	50,227.9
	Annual Total			29,003.265	18,061,769.5	18,333,183.5

[1] Information supplied by Mr. Jack Rydquist, Sanitary Engineer, Municipal Wastewater Division Bureau of Water Management, Michigan Department of Natural Resources (1974).

[2] Information from Epstein et al. (1974).

Table 14. Inputs to Green Bay from paper mills (1974).

State	Paper Mill	Primary receiving water	Mean discharge (MGD)	Mean BOD^5 (lb./day)	Mean Suspended Solids (lb./day)
Mich. [1]	Escanaba Paper Mill [2]	Escanaba River	27.294	8,372	15,007
	American Can Co.[3]	Menominee River	2.093	925	436
Wisc. [4]	Scott Paper Co.	Menominee River	4.619	1,755	2,985
	Badger Paper Mills	Peshtigo River	4.547	40,052	6,546
	Scott Paper Co.	Oconto River	11.198	51,035	7,880
	Green Bay Packaging Inc.	Fox River	1.786	1,355	465
	Charmin Paper Co.	Fox River	14.522	43,802	12,674
	American Can Co.	Fox River	11.214	32,241	7,257
	Fort Howard Paper Co.	Fox River	17.498	4,654	12,342
	Nicolet Paper Co.	Fox River	3.299	586	977
	Thilmany Pulp & Paper Co.	Fox River	22.749	16,213	17,684
	Appleton Papers	Fox River	7.159	16,664	6,007
	Kimberly-Clark, Kimberly Mills	Fox River	37,211	8,196	14,244
	Consolidated Paper Co.	Fox River	8.219	35,944	9,454
	Riverside Paper Co.	Fox River	0.840	390	747
	John Strange Div. Menasha Corp.	Fox River	1.506	1,010	1,168
	Gilbert Paper Co.	Fox River	0.021	16	369
	George A. Whiting Co.	Fox River	0.562	532	1,415
	Kimberly-Clark, Lakeview Mill	Fox River	4.574	1,313	618
	Bergstrom Paper Co.	Fox River	4.527	20,217	15,473
	Total (Daily)		185.438	285,272	133,748
	Annual Total		67,684.870	104,124,382	48,818,173

[1] Means calculated from data in Monthly Industrial Self-Monitoring Reports supplied by Comprehensive studies Section, Bureau of Water Management, Michigan Department of Natural Resources

[2] Means calculated from data for May - April, 1974.

[3] Means calculated from data for November, 1973 - May, 1974.

[4] Data from Epstein et al. (1974).

Algal Assemblages

Experiments were conducted with actinomycete isolates and algal cells collected from Green Bay to assess the latter's effect on actinomycete growth. Water collected by the Wisconsin Department of Natural Resources on July 9, 1974 in southern Green Bay was air-shipped to Michigan. The collection area is station four in the Green Bay-Fox River Special Attention Area Study (EPA Contract No. 68-01-1572 -Wisconsin Department of Natural Resources, 1973). It is located in lower Green Bay between Long Tail Point and Grassy Island in the vicinity of the shipping channel. Algal density and composition is given in Table 15.

Table 15. Algal composition of water sample from southern Green Bay (July 9, 1974).

Taxa[1]	cells/ml[2]	Relative Abundance (%)	Chlorophyll a (µg/l)
Blue-greens	1,360.8	47.1	
Diatoms	932.7	32.8	26.6
Greens	489.3	16.9	
Dinoflagellates	107.0	3.7	
Total	2,889.8	100.0	

[1] Determined by Wisconsin Department of Natural Resources (D. Patterson, Wisconsin DNR, personal communication).

[2] Colonial, filamentous and single cell forms each counted as one.

Six liters of lake water were vacuum filtered with a membrane filter (0.45 µ pore size). The algae were then resuspended in distilled water in quantities sufficient to make concentrations of 0.3, 0.6, 3.0, 6.0, and 12 times the original concentrations of algae in the bay water. Triplicate 50 ml cultures were prepared and autoclaved for 25 minutes at 15 psi. The cultures were then inoculated with 1 ml of actinomycete isolate E_{1a} (spore suspension) and incubated at 24-28°C for three weeks.

Growth was observed at all algal cell concentrations (Figure 16) and an earthy-musty odor was produced. Upper limiting concentrations of algae were not determined. The initial and 21-day mean actinomycete abundance were statistically ($p < 0.05$) different (Tukey's w-procedure)

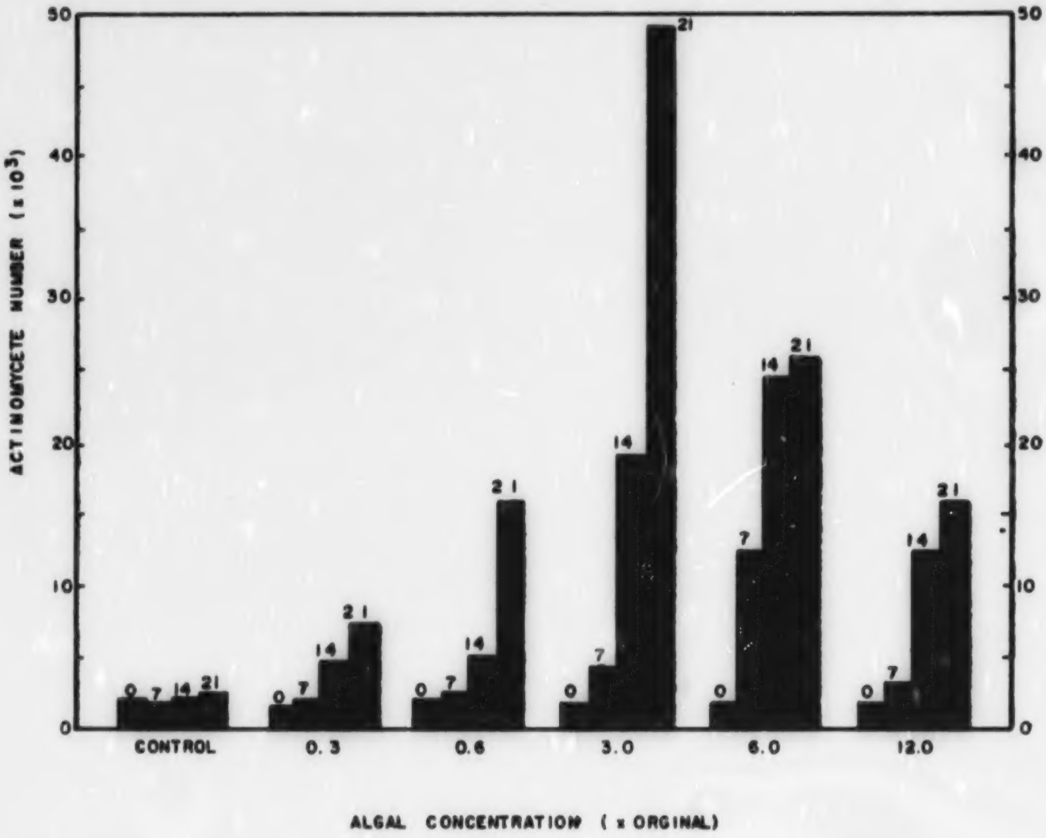


FIGURE 16. GROWTH OF ACTINOMYCETE ISOLATE E1a WITH ALGAL CELLS AS SOLE ENERGY SOURCE. ACTINOMYCETE GROWTH MEASURED AT 0,7,14, AND 21 DAYS.

for all experimental algal cell concentrations. The conclusion is rather clear. Actinomycetes from northern Green Bay are able to utilize dead algal cells as an energy source.

The implications of such an energy pathway are important. Algal population size in North American temperate climate lakes is controlled, to a large degree, by the availability of inorganic nutrients. Annual increases in inorganic loadings (especially phosphorus) to a lake system produces an increase in algal standing crop (increased eutrophy). As the algal cells die, they become available as an energy source for actinomycete growth. When algal standing crops are large and/or primary productivity high, it would be anticipated that the actinomycete standing crop should also be larger. Indirectly, then, the annual input of inorganic nutrients could stimulate actinomycete growth. Eutrophication of the Great Lakes does not go unnoticed by the decomposer fraction. They are causally linked to the primary production components.

Actinomycete, Earthy-Musty Odor Relationship

In defining odor problems for water supplies there appear to be three broad categories under which odors can be defined with fairly good agreement. These are 1) chemical odors, 2) fishy odors, and 3) grassy, earthy or musty odors. As a first approximation, these are usually the result of 1) chemical spills or waste effluent discharges, 2) diatoms and 3) algae or actinomycetes, respectively.

Isolated actinomycete strains produced an earthy-musty odor. Four were *Streptomyces*, one a probable *Streptomyces* and one a probable *Micromonospora*. Isolate E_{1a}, in particular, produced a musty odor under a wide variety of conditions. This observation was checked further. E_{1a} was inoculated into distilled water brotha containing only one of the following compounds; arabinose, glucose, glycerol, inositol, lactose, maltose, mannitol, raffinose, starch, sarbitol, sucrose, xylose or chitin. After three weeks of incubation (24-28°C), only the raffinose, xylose and distilled water control cultures exhibited little or no growth. However, the odors produced varied; only the E_{1a}, isolate in glucose, inositol and starch produced a strong musty odor. All the other compounds, including raffinose and xylose, induced a sweet or medicinal odor from the actinomycete isolate. While this experiment needs further confirmatory work, it does indicate there may be a relationship between odors produced and the type of organic nutrients available in the aquatic ecosystem.

It was also found that the presence of odor is related to the presence of actinomycete spores. Yeast extract cultures of E_{1a} were incubated for 14 days (24-28°C) and then vacuum filtered (membrane filters, 0.45 μ). The collected mycelium-spore mass was resuspended in an equal volume of distilled water. Actinomycete counts and TON were determined for the original culture, the resuspended mycelium-spore mass and the filtrate (Table 16).

Table 16. Relationship of earthy-musty odor and mycelia-spore mass of Isolate E_{1a}.

	Actinomycete count	TON
Actinomycete culture	70,000	3094
Resuspended actinomycetes	60,000	29
Filtrate	0	3094

It is apparent that the earthy-musty odor is due to a metabolite of the actinomycetes and not the colonies themselves, as has been shown by many investigators (Romano and Safferman, 1963; Gerber, 1968; Gerber and Lechevalier, 1965; Rosen et al., 1970). The low TON in the resuspended actinomycete solution is probably due to metabolite remaining on the spores and mycelin masses, since the filter was not rinsed until odor free before resuspension of the mycelium mass. The TON of the filtrate also decreased from 3094 to 1165 during a two week refrigeration period. This clearly shows that the metabolite is dissipated (physically or biologically) with time.

DISCUSSION

The geographic abundance of actinomycetes in the Great Lakes and northern Green Bay (Lake Michigan) and causal factors responsible for the observed population distribution are discussed in light of the following ecologic principles. Individuals of a population must be supplied with certain essential materials in order to grow and multiply. Not only must specific essential elements be present, but each element to which the organism responds has a maximum and minimum limiting effect. These observations are usually stated as Liebig-Blackman law and Shelford law (Boughey, 1968). Thus, an organism's success in populating a given ecosystem is controlled by the availability of limiting elements and physical factors and by the limits of tolerance of an organism to these factors and competing organisms (Odum, 1971). Actinomycete populations are controlled by these principles. As such, actinomycete growth and reproduction is intrinsically intermeshed with the energy flow and mineral cycles in the Great Lakes.

The enrichment of the Great Lakes, and Green Bay specifically, over time is a fact. There has been an increase in biological production at the primary producer level and an increase in the dissolved nutrients within the lakes (Beeton, 1969; Stoermer, Schelske and Feldt, 1971; Ladewski and Stoermer, 1973; Vollenweider _et al_., 1974; Dobson _et al_., 1974; and Patterson _et al_., 1975.). The general observation drawn from the above references is that nearshore stations and major embayments are nutrient enriched and support a greater level of primary production than offshore or midlake stations. Our results indicate actinomycetes, like the other decomposer organisms (e.g., bacteria, fungi), also increase (greater numbers and biomass) in lake zones with higher primary production.

Our laboratory growth studies suggest that a wide variety of organic substances are capable of stimulating the growth of _Streptomyces_ organisms. These organisms, in turn, produce the objectionable earthy-musty odor when grown on most of the materials. Phenol and cellulose stimulate actinomycete growth when present in low concentrations and when certain mineral salts are available. Paper mill and secondary municipal effluents containing organic compounds also stimulate actinomycete growth. Organic material enters Green Bay from wastewater treatment plant and paper mill effluents. Additional organic material enters Green Bay from cannery and milk processing wastes, agricultural runoff and natural sources. Furthermore, since all effluents are diluted as they disperse into the receiving waters, the fact that the laboratory results indicate the dilution of concentrated organic materials increases actinomycete growth is very important. Our studies, then, indicate rather clearly that the point and non-point source organic enrichment of northern Green Bay directly enhances conditions for increased actinomycete growth.

Inorganic nutrient enrichment will also stimulate actinomycete growth, but in an indirect manner. The addition of inorganic nutrients such as phosphorus and nitrogen, to nutrient limited lakes will usually result in increased algal standing crops. Since our laboratory results indicate algal cells are a carbon source for actinomycetes and do enhance growth, the end result of increased annual nutrient loadings to the bay will be an environment more suitable for actinomycete growth.

Additionally, many industrial-municipal and non-point organic materials often contain resistant organic compounds (such as cellulose, lignin, chitin, rubber) which actinomycetes can decompose (Umbreit and McCoy, 1941; Erickson, 1940; Leeflang, 1963), but most bacteria can not. This would seem to further favor increases in actinomycete populations, since they lack competitors for these energy sources.

It is also ecologically important that the earthy-musty odors is due to a metabolite produced by actinomycetes and not the actinomycete colonies themselves. The metabolite can be produced by actinomycetes in one area and carried by currents to different areas. Currents are variable and change with season and wind patterns. This makes it very difficult to pinpoint the specific areas where the metabolite is produced.

A preliminary investigation of the severity of the Green Bay odor problem revealed that many other areas of the Great Lakes had experienced similar problems. Our laboratory and field investigations included other areas of the Great Lakes, both with and without histories of odor problems. These investigations indicated that the following parameters were generally higher in areas with a history of odor problems than in areas without odor problem histories: 1) total organic carbon and chlorophyll a concentrations, (i.e., a high degree of eutrophication); 2) actinomycete number; and 3) percent of *Streptomyces* in the total actinomycete population. The areas in Green Bay (Escanaba, Gladstone and Menominee) fit these observations quite well.

It must be remembered that there were not severe odor outbreaks in northern Green Bay during the study period. However, our over-all results support the hypothesis that earthy-musty odor problems in Green Bay and other areas of the Great Lakes are due to the inorganic and organic nutrient enrichment which directly and indirectly support larger actinomycete populations. These in turn produce the associated earthy-musty odor.

Other investigators have suggested such a relationship. McMillan *et al.*, (1972) hypothesized that odor problems in water from southern Lake Michigan used by the City of Chicago were caused by increased populations of actinomycetes. This was attributed to the nearshore pollution of Lake Michigan. Bays *et al.*, (1970) found that actinomycete growth was more highly stimulated by sterilized river water with a high degree of organic enrichment than water with low organic enrichment.

Theoretically, this hypothesis is ecologically sound. Actinomycetes are decomposers, and, as such, are limited by substrate and nutrient availability. Nutrient and organic enrichment provides suspended solids and organic material which actinomycetes can colonize and decompose. Increasing the nutrient-substrate complex reduces the effect of these limiting factors on actinomycete growth. Larger standing crops of actinomycetes would then produce the odor-causing metabolites in sufficient quantities to cause taste and odor problems. Further long-term, intensive surveys at specific areas before and during odor outbreaks are needed to further confirm this hypothesis.

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Appendix A

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Appendix B

Station Location

Northern Green Bay

1974

STATION LOCATION

1) Control (C) - Big Bay de Noc off Middle Bluff in 14 meters of water. Sitings: 26° to buoy (BS 1) on Big Bay de Noc Shoal (0.5 miles); 54° to Garden Bluff; 277° to south end of Round Island. Latitude: 45° 44' 26". Longitude: 86° 42' 32".

2) Open Water #1 (OW1) - Open water station in the mouth of Little Bay de Noc in 16 meters of water. Sitings: 110° to Peninsula Point (2.6 miles); 175° to Minneapolis Shoals Light; 345° to apartment tower in Escanaba. Latitude: 45° 40' 47". Longitude: 87° 1' 7".

3) Open Water #3 (OW3) - Green Bay open water station in 22 meters of water. Sitings: 90° to northern most large smoke stack in Menominee (3.2 miles); 153° to east end of Green Island; 89° to southern smoke stack in Menominee. Latitude: 45° 5' 57". Longitude: 87° 31' 22".

4) Gladstone (G) - Little Bay de Noc in the vicinity of the Gladstone municipal water intake in 13 meters of water. Sitings: 4° to Saunders Point (0.3 mile); 201° to Squaw Point; 250° to Gladstone Yacht Harbor point. Latitude: 45° 50' 34". Longitude: 86° 54' 52".

5) Escanaba (E) - Little Bay de Noc in the vicinity of the Escanaba municipal water intake in 16 meters of water. Sitings: 342° to Escanaba Light (1000 feet); 217° to south tip of Sand Point; 280° to apartment tower in Escanaba. Latitude: 45° 44' 37". Longitude: 87° 2' 10".

6) Menominee (M) - Green Bay in the vicinity of the Menominee municipal water intake in 7 meters of water. Siting: 270° to north tip of seawall around yacht harbor (1000 feet). Latitude: 45° 6' 38". Longitude: 87° 35' 56".

7) Portage Marsh #1 (PM 1) - Portage Marsh at marsh-bay interface in 1.2 meters of water. Sitings: 33° to Sand Point (2 miles); 175° to Portage Point. Latitude: 45° 43' 9". Longitude: 87° 3' 35".

8) Portage Marsh #2 (PM 2) - Little Bay de Noc off Portage Marsh in the vicinity of the Escanaba Wastewater Treatment Plant outfall in 11 meters of water. Sitings: 245° to Portage Point; 20° to Sand Point; 133° to Peninsula Point. Latitude: 45° 42' 43". Longitude: 87° 3' 9".

Appendix C

Hydrochemistry of Northern Green Bay (Lake Michigan)

Hydrochemistry of Northern Green Bay (Lake Michigan)

This section deals with the documentation of nineteen chemical parameters as well as transparency and chlorophyll a determinations. The basic data from each survey date is provided in Appendix D for future reference. When possible, interstation and seasonal differences were noted. Additionally, the limnological characteristics of northern Green Bay were compared to other Great Lakes and embayments. To simplify the comparisons, when possible, the most recent literature is used. Also, the data was treated in such a manner that it is represented in a similar scale to the cited literature.

MATERIALS AND METHODS

Data was gathered from northern Green Bay (Lake Michigan) in 1974. Eight stations were sampled on 5 occasions (April, May, July, September and October). On site determinations included transparency (Secchi disc), dissolved oxygen, pH and temperature using Martek, Yellow Springs and Sargent-Welch field monitors. Chlorophyll a was determined from composite water samples. A composite sampler, modeled after one developed for the "Recreational Lakes Water Quality Evaluation Programme, Ontario Ministry of the Environment (Schenk, personal communication) was used. A sample was obtained to a depth twice the transparency measurement and arbitrarily defined as the euphotic zone.

Chemical samples were stored in plastic bottles (1 liter) and refrigerated (4°C). Nutrients were treated similarly, but were placed in 125 ml glass bottles and chlorophyll a samples were placed in 1 liter plastic bottles and preserved with 5-10 drops of saturated magnesium carbonate solution.

The hydrochemical parameters were assessed by staff at the University of Michigan Biological Station, Pellston, Michigan. Chloride, sulfate, silica, total alkalinity, turbidity and organic nitrogen were analyzed according to Standard Methods (American Public Health Association, 1971). Ammonia and nitrate-nitrogen were colorimetrically determined on a Beckman DB-GT Spectrophotometer after methods of Solorazano (1969) and Muller and Wildemann (1955), respectively. Total and soluble-reactive phosphorus samples were digested by the method of Gales et al., (1966) while neutralization and color development followed Schmid and Ambuhal (1965) prior to colorimetric determination on a Beckman DB-GT Spectrophotometer. An Industrial Instruments Model RC-16B2 Conductivity Bridge was used to measure conductivity and color was measured using platinum cobalt standards (Hach Chemical Company, 1974). For the determination of chlorophyll a, a Turner Model III Fluorometer was used following extraction with 90% acetone (Strickland and Parson, 1968). Total dissolved solids, suspended solids and volatile solids were gravimetrically determined (EPA manual, 1971). A Perkin-Elmer Model 305 Atomic Absorption Spectrophotometer was used to measure calcium, magnesium, sodium and potassium (EPA manual, 1971).

Total organic carbon samples from the Great Lakes were collected in May and October only. One liter samples were preserved with 40 mg/l mercuric chloride and refrigerated. Determinations were performed on a Beckman Carbon Analizer by personnel from the Institute of Water Research, Michigan State University.

RESULTS - CONCLUSIONS

Dissolved Oxygen - Temperature

The average dissolved oxygen concentration in middle and northern Green Bay was 11.2 mg/l (97.5% saturation) throughout the ice-free season (Figure C-1). Typically, maximum dissolved oxygen and percent saturation occurred at spring (April) and fall (October) overturn as expected for a northern temperate climate lake (Appendix D).

When and where thermal stratification did occur, the average dissolved oxygen concentration in the hypolimnion was 8.3 mg/l (77.7% saturation). Oxygen conditions in the hypolimnion during summer stratification for each station are indicated in C-2. The Big Bay de Noc and nearshore middle Green Bay (Menominee) stations did not stratify. The offshore middle Green Bay station was also stratified at the time of the September survey. Lowest percent oxygen saturation occurred at the Gladstone station in Little Bay de Noc. It can generally be noted that the oxygen condition of the hypolimnion was lower in Little Bay de Noc and middle Green Bay compared to upper Green Bay and Big Bay de Noc stations. Over-all, northern Green Bay and its embayments are well oxygenated. Compared to oxygen conditions in lakes Superior, Huron, Erie and Ontario near the end of summer stratification (Figure C-3), northern Green Bay is positioned betwen Ontario and Erie (Dobson et al., 1974).

The temperature regime is similar to Lakes Michigan and Huron and higher than Lake Superior. Seasonal maximum temperature observed was 21°C on July 27-28. The average surface temperature for the ice free period was 10°C.

Major Ions - Alkalinity - pH

Figure C-4 lists the average concentration of major ions (Ca, Mg) Na, K, SO_4, Cl) in northern Green Bay. Northern Green Bay is similar to Lakes Superior, Huron and Michigan in concentration and relative abundance (Ca > Mg > Na > K) of the major cations (Weiler and Chawla, 1969). Sulfate concentration (Figure 5) are higher than Lake Superior (3.9 ppm) equal to Huron (17.2 ppm) and Michigan (13.5 ppm) and lower than Erie (25.7 ppm) and Ontario (29.4 ppm). Chloride follows the same distribution except northern Green Bay is slightly higher than Huron and Michigan (Weiler and Chawla 1969). The average chloride level throughout northern Green Bay is 11.1 mg/l. Although the Little Bay de Noc stations had a lower average value (9.9 mg/l), the chloride concentration doubled from 1960 to 1968 (Ryckman, 1968) period and is at the latter level in 1974. However, no significant change in Ca and Na has occurred in the last 14 years.

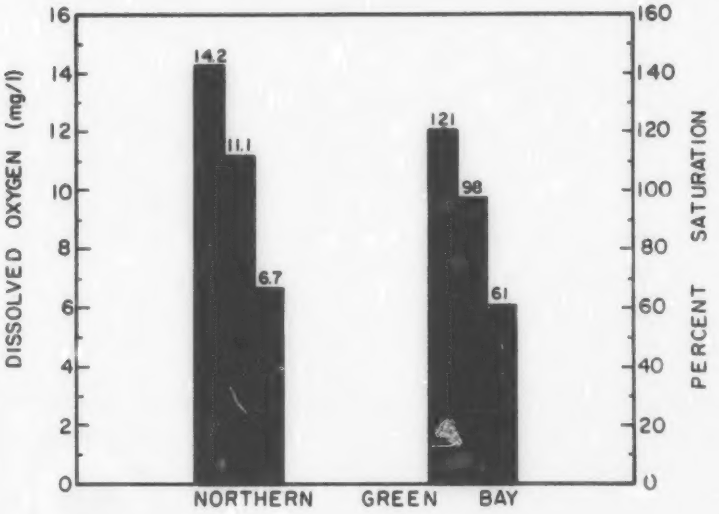

FIGURE C-1. MEAN D.O. AND PER CENT OXYGEN SATURATION FOR NORTHERN GREEN BAY (LAKE MICHIGAN) APRIL 24-OCTOBER 29, 1974, MAXIMUMS AND MINIMUMS ALSO INDICATED.

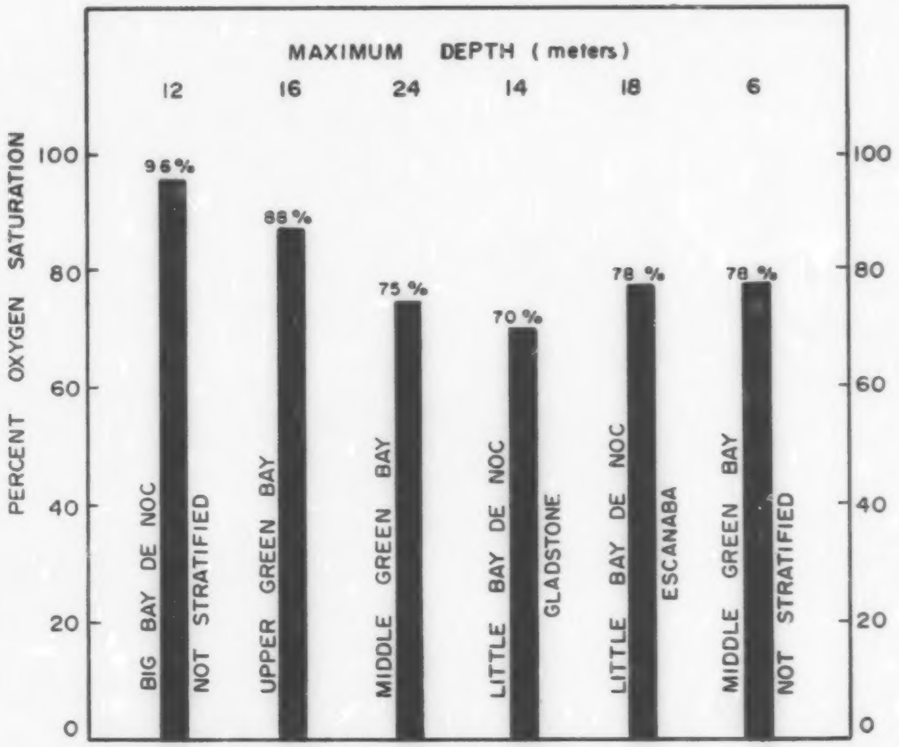

FIGURE C-2. MEAN OXYGEN (% SATURATION) VALUES IN HYPOLIMNION OF STATIONS IN NORTHERN AND MIDDLE GREEN BAY DURING SUMMER STRATIFICATION, JULY 27-28, 1974

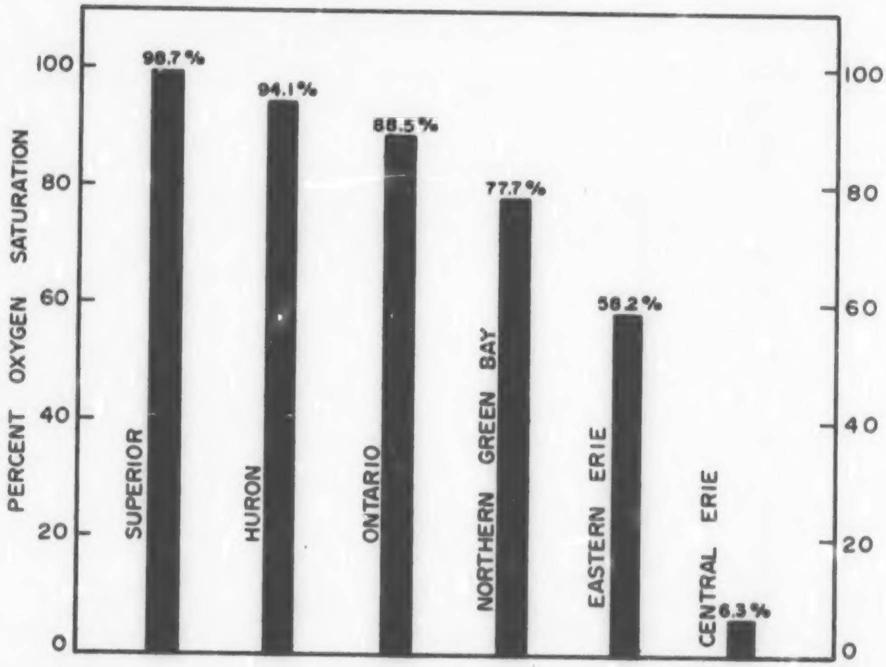

FIGURE C-3. MEAN OXYGEN PERCENT SATURATION VALUES IN HYPOLIMNION OF NORTHERN GREEN BAY (LAKE MICHIGAN) COMPARED WITH OTHER GREAT LAKES (FROM DOBSON et. al., 1974)

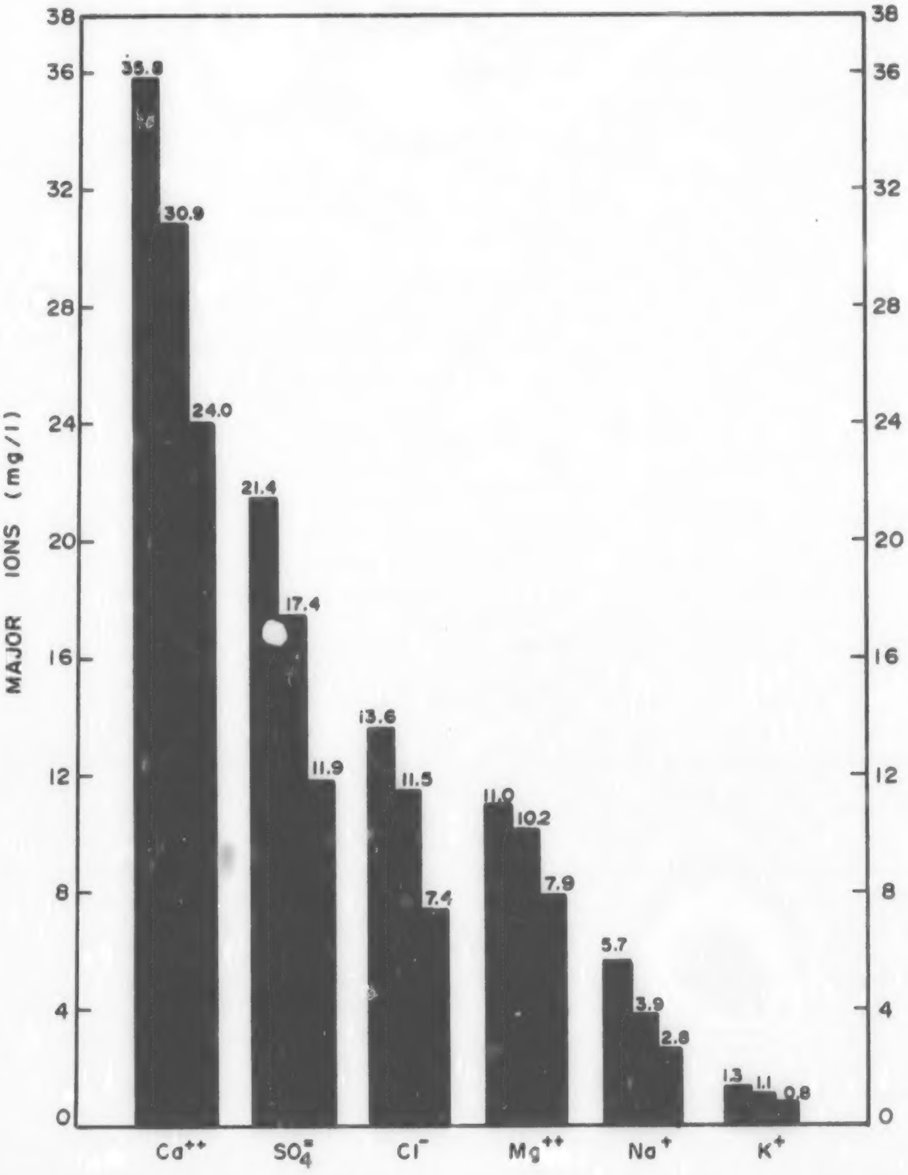

FIGURE C-4. AVERAGE CONCENTRATION OF MAJOR IONS IN NORTHERN GREEN BAY (1974). DATA FOR EACH PARAMETER ARE GIVEN AS MEAN FOR ALL DEPTHS. SAMPLES OBTAINED AT SPRING OVERTURN (APRIL) EXCEPT FOR CHLORIDE WHICH WAS MEASURED IN JULY. MAXIMUM AND MINIMUM VALUES ARE INDICATED.

Alkalinity of northern Green Bay ranged from 103 to 114 mg/l (Appendix D). Again, site variation is not evident. Alkalinity in northern Green Bay is lower than southern Green Bay and similar to Lake Michigan. Northern Green Bay and Lake Michigan concentrations are greater than Superior, Huron, and Erie.

The pH of northern Green Bay ranged from 8.2 to 8.4 (Appendix D), which is similar to average values for Michigan, Huron, Erie, and Ontario (usually >8.0) and higher than Superior (Weiler and Chawla, 1969).

Conductivity - Total Dissolved Solids

Average conductivity and total dissolved solids values in northern Green Bay ranged from 230 to 345 µmho and 127 to 180 mg/l, respectively. Site and seasonal (Appendix D) variation are minimal. Compared to other Great Lakes and embayments, the waters of northern Green Bay have conductivity levels similar to Michigan, Erie (western basin) and Saginaw Bay, but lower than Erie (central basin) and southern Green Bay and higher than Huron and Superior. Northern Green Bay total dissolved solids concentrations are similar to northern Lake Michigan, lower than southern Green Bay, Ontario and Erie, and higher than Huron and Superior.

Secchi Depth

Transparency in northern Green Bay is indicated in Figure C-5. It is evident that Big Bay de Noc and the upper Green Bay station had the greatest transparency throughout the ice-free period (April-October). Little Bay de Noc and middle Green Bay stations were similar. But the similarity was not due simply to phytoplankton standing crop variation (as measured by chlorophyll *a*). Both Menominee nearshore and offshore stations had higher average chlorophyll *a* concentrations, but the lowest annual transparency values were in Little Bay de Noc (Gladstone and Escanaba stations). True color differences due to the presence of dissolved organic compounds is primarily responsible for the observed differences. Little Bay de Noc had a brown coffee color cast to the water which was not evident in middle Green Bay (Menominee nearshore and offshore). True color in the former seasonally averaged 31 (pt-co units) compared to 25 for the latter (Appendix D).

Figure C-6 is a smooth curve adapted from Dobson *et al.*, (1974) to indicate the relative transparency of northern Green Bay and southern Green Bay (Patterson and Epstein, 1975) with the other Great Lakes. According to Dobson *et al.*, (1974) Secchi reciprocals (30/SD) are approximate indicators of particulate matter. In terms of either transparency or 30/SD values, northern Green Bay had a higher transparency than southern Green Bay, western Erie, and Ontario (June-October only). It has an average Secchi depth value of 3 meters which is representative of a meso-eutrophic placement based on data from Dobson *et al.*, (1974).

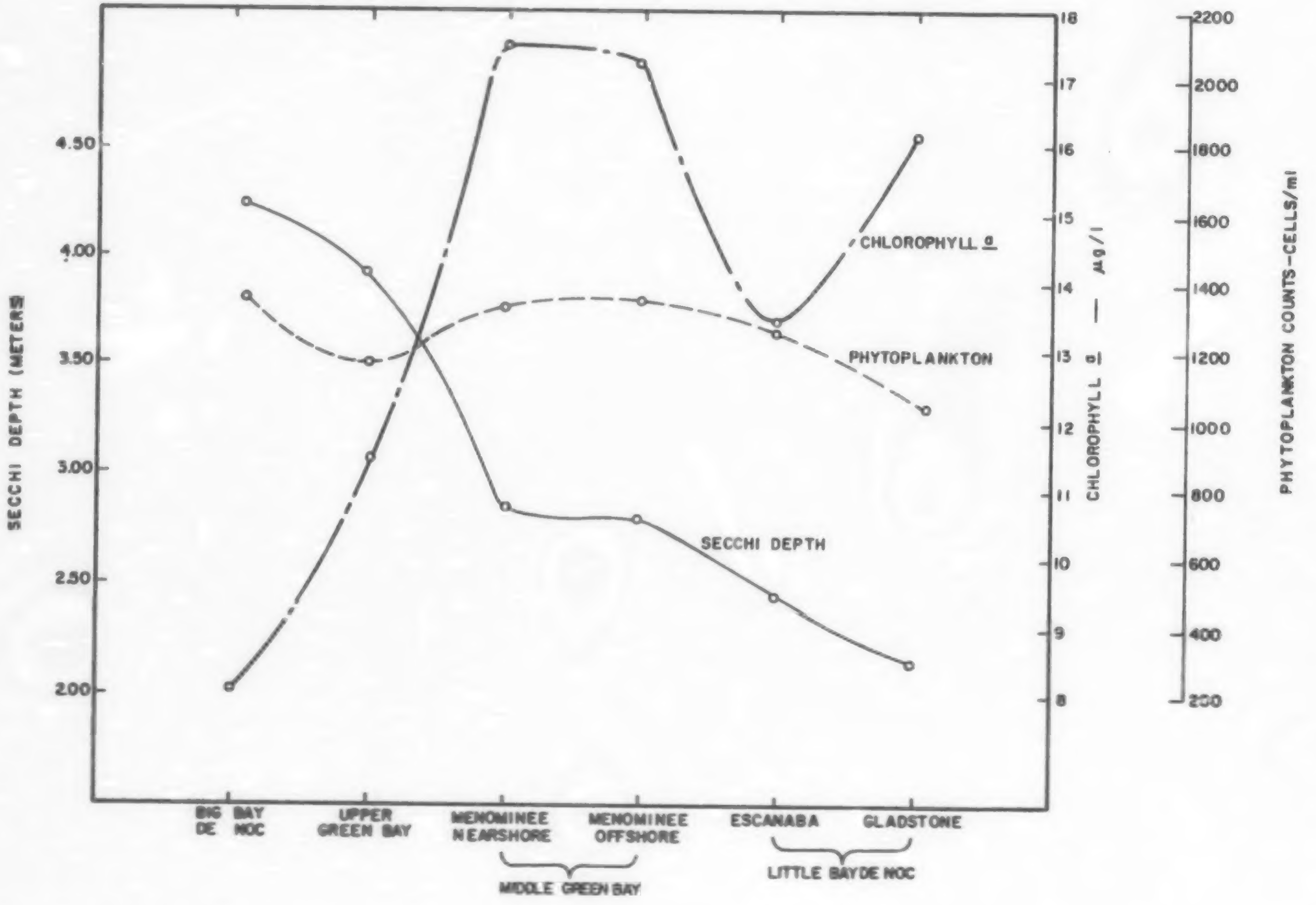

FIGURE C-5. AVERAGE SECCHI DEPTH VALUES, CHLOROPHYLL a CONCENTRATION AND PHYTOPLANKTON NUMERICAL ABUNDANCE FOR STATIONS IN NORTHERN GREEN BAY THROUGHOUT ICE-FREE PERIOD (APRIL-OCTOBER) OF 1974

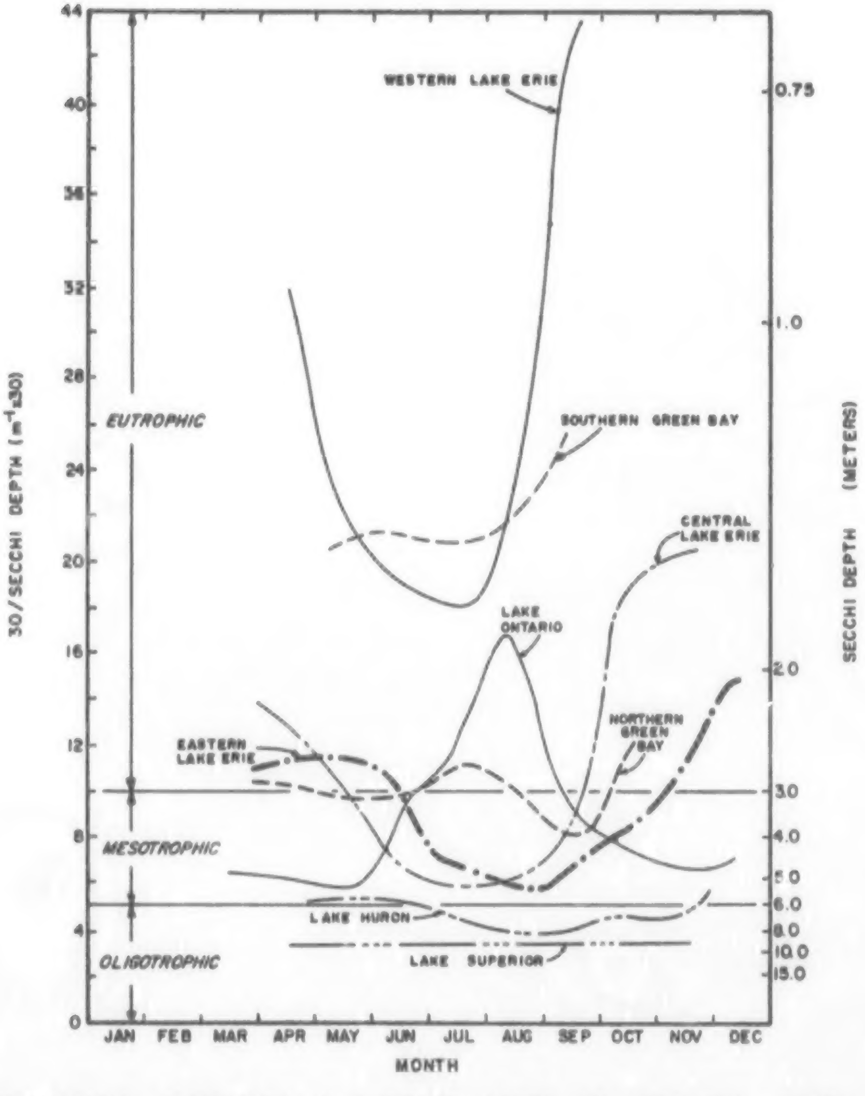

FIGURE G6. SEASONAL TURBIDITY IN SURFACE WATER OF NORTHERN GREEN BAY (LAKE MICHIGAN) AS INDICATED BY MEAN SECCHI DEPTH MEASUREMENTS OBTAINED FROM FIVE SURVEYS (APRIL - OCTOBER) IN 1974 COMPARED WITH OTHER GREAT LAKES (FROM DOBSON et. al., 1974). SOUTHERN GREEN BAY DATA IS FROM PATTERSON AND EPSTEIN, 1975.

Reactive Silica

Concentrations of reactive silicate in surface waters (1 meter) for each of the study areas are shown in Figure C-7. Station differences are observable (Big Bay de Noc and upper Green Bay < Little Bay de Noc and Menominee - offshore < Menominee - nearshore). A seasonal trend was also present (Appendix D). The average spring (April) concentration was approximately double the summer (May-October) concentration. The spring, summer and annual means were 1085, 492 and 610 µg/l, respectively. The summer average for northern Green Bay compared favorably with concentrations observed by Schelske and Callender (1970) in 1969. There is no noticeable change in silicate concentration over the last five years.

Reactive silica concentrations in northern Green Bay are very similar to Huron and western Erie, approximately one-half of Lake Superior and more than double the winter concentrations in Erie (central and eastern basin) and Ontario (Dobson et al., 1974). Summer concentrations are approximately double northern Lake Michigan (Schelske and Callender, 1970). Dobson et al., (1974) indicates the difference between winter and summer concentrations of dissolved silicate reflect the relative intensity of silicate metabolism by the diatom fraction of the phytoplankton population. Northern Green Bay had a 597 µg/l decrease, this was very similar to Dobson's et al. (1974) findings for Huron (536 µg/l) which he regarded as anomalously high and attributed to abundant diatom populations in an early stage of "eutrophication" (Figure 8).

Particulate Phosphorus

Schelske and Stoermer (1972) have related phosphorus to eutrophication of Lake Michigan through the correlation of particulate phosphorus to rates of phytoplankton carbon fixation. Particulate phosphorus concentrations in lakes is an indirect measure of the degree of primary production. Lakes with greater quantities of particulate phosphorus are considered more eutrophic or nutrient-rich. Dobson et al., (1974) compared the Great Lakes (except Michigan) particulate phosphorus concentrations. Northern Green Bay's relative ranking is indicated in Figure C-9. Based on Dobsons et al. (1974) trophic range, northern Green Bay is mesotrophic and similar to Lakes Ontario and Erie (eastern and central basin).

Nitrate and Ammonia Nitrogen

Surface water (1 meter) concentrations of nitrogen (nitrate + ammonia) for spring overturn and the summer period of northern Green Bay are included with Dobson's et al. (1974) comparison of other Great Lakes (Figure C-10). It has a spring/winter concentration similar to Superior, Huron and Ontario. However, the degree of nitrogen metabolism as illustrated by differences between spring and summer values (175 µg/l) is not similar to Huron and Superior. Rather, it is similar to Ontario and Erie (Dobson et al. 1974). The summer

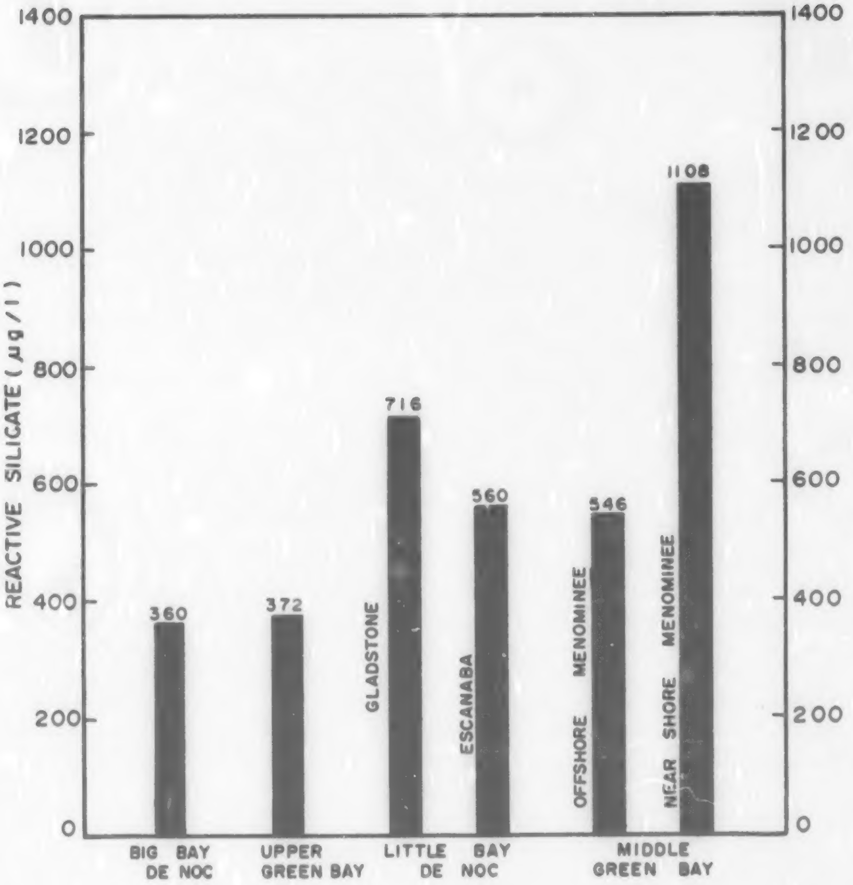

FIGURE C-7. AVERAGE REACTIVE SILICATE CONCENTRATIONS IN SURFACE WATER (1 METER) OF NORTHERN GREEN BAY DURING ICE FREE PERIOD. (APRIL- OCTOBER OF 1974).

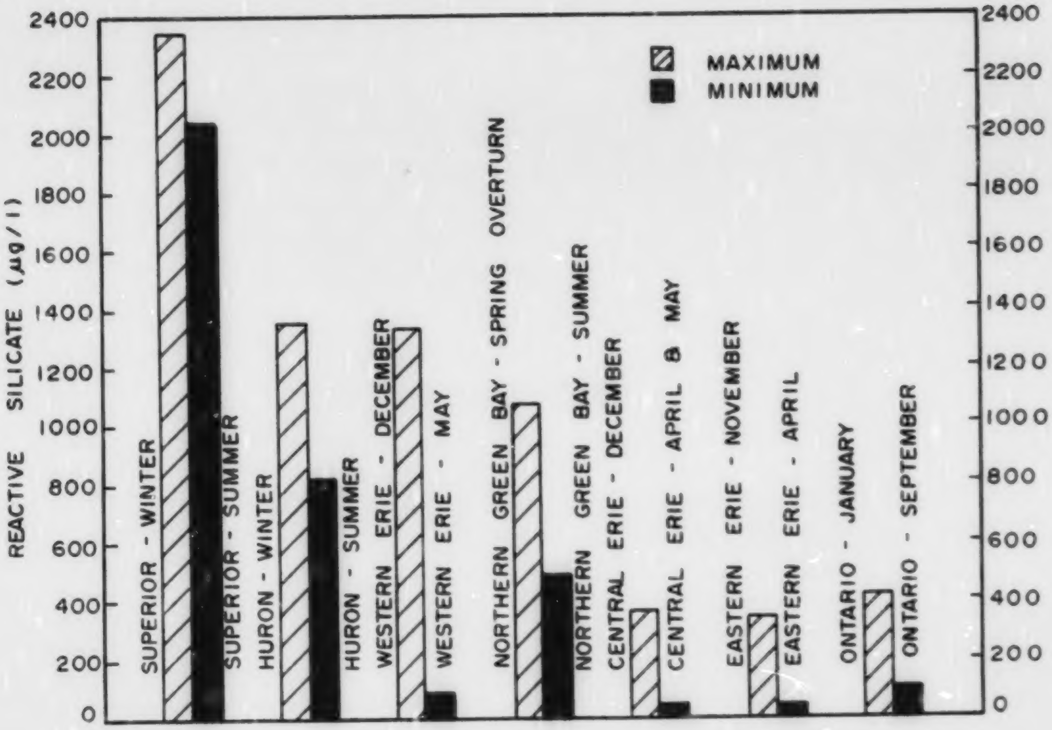

FIGURE C-8. AVERAGE REACTIVE SILICATE CONCENTRATIONS IN SURFACE WATER (1 METER) NORTHERN GREEN BAY COMPARED WITH OTHER AREAS OF THE GREAT LAKES (FROM DOBSON et. al, 1974).

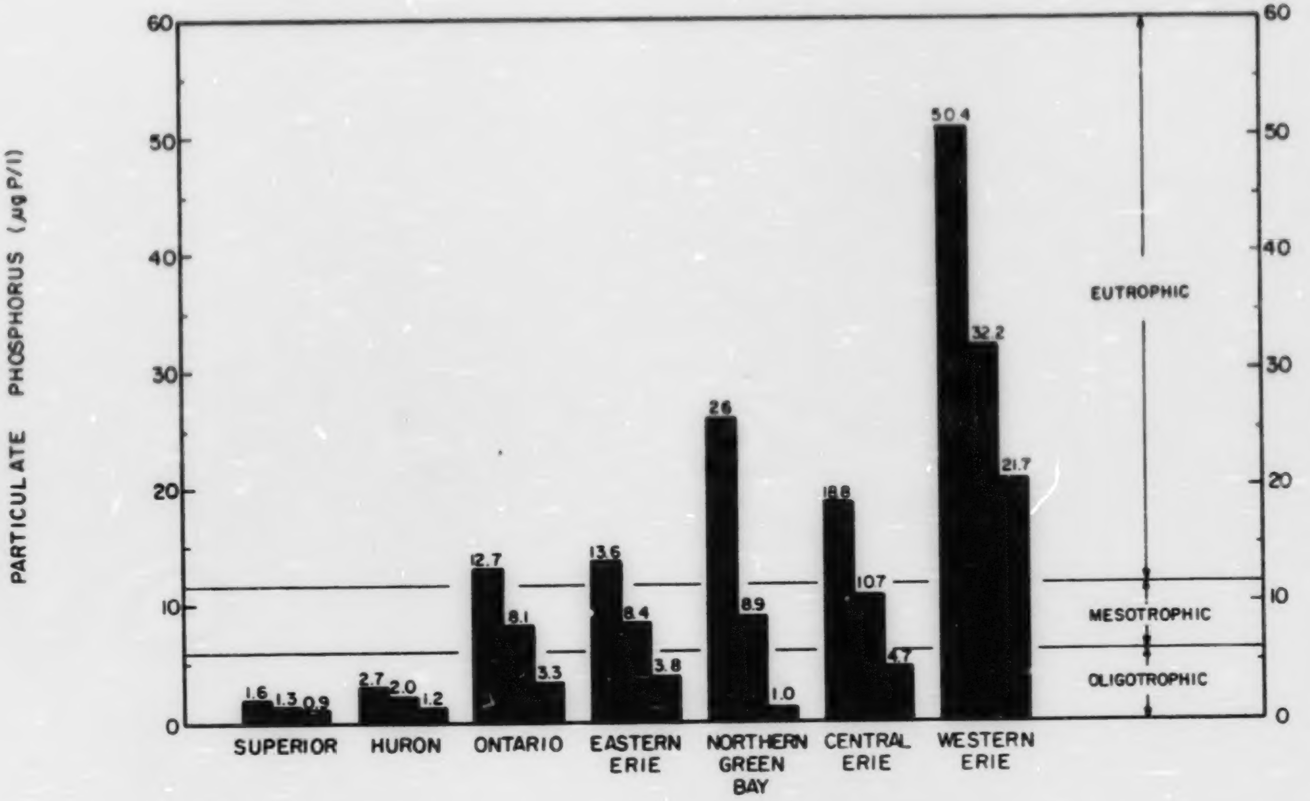

FIGURE C-9. AVERAGE, MAXIMUM AND MINIMUM PARTICULATE PHOSPHORUS CONCENTRATIONS IN SURFACE WATERS (1 METER) OF NORTHERN GREEN BAY (1974) COMPARED WITH OTHER GREAT LAKES. DATA ON GREAT LAKES AND TROPHIC RANGE ARE FROM DOBSON et. al. (1974).

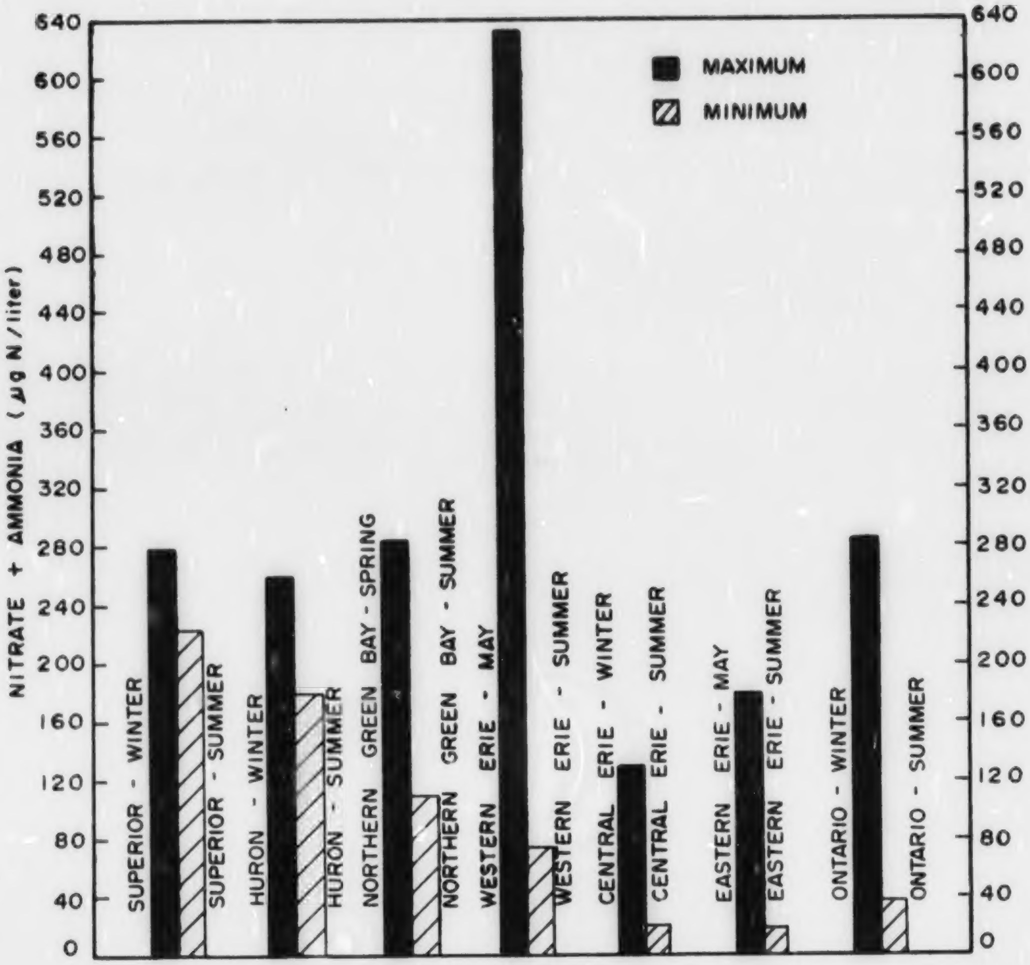

FIGURE C-10. SURFACE WATER (1 METER) MEAN CONCENTRATION OF NITRATE + AMMONIA IN NORTHERN GREEN BAY (1974) COMPARED WITH OTHER GREAT LAKES (FROM DOBSON et. al., 1974) nitrogen depletion in surface waters of the latter lakes is indicative of a more biologically productive situation.

Chlorophyll a

No comprehensive studies have been made on the temporal and spatial distribution of chlorophyll a in northern Green Bay (Lake Michigan). The present study examined this distribution. The results are shown in Figure C-11. Big Bay de Noc had the lowest concentration and middle Green Bay (Menominee - nearshore and offshore) the highest. Little Bay de Noc has a slightly lower average concentration than middle Green Bay, but based on the range of maximum-minimum values, it is essentially similar to the latter. The upper Green Bay station was also related more to Little Bay de Noc and middle Green Bay than Big Bay de Noc. This is illustrated clearly when Dobson's et al. (1974) trophic ranges (mesotrophic - 4.4 to 8.8 μg/liter) are applied to northern Green Bay. Only Big Bay de Noc falls into the mesotrophic range while the other stations are in the eutrophic field.

Figure C-12 illustrates the abundance of chlorophyll a in the surface waters of northern Green Bay relative to measurements on the Great Lakes (Dobson et al., 1974). It is similar to western Erie and greater than Erie, (central and eastern), Ontario, Huron and Superior. Compared to Lake Michigan (∿2μg/l), northern Green Bay had chlorophyll a concentrations approxiamtely four - five times greater than northern Lake Michigan, (Schelske and Roth, 1973; Robertson et al., 1971). However, southern Green Bay (Patterson and Epstein, 1975) is approximately two-fold higher than northern Green Bay (Figure C-12). There is a clear ranking between the north and south portion of the embayment and Lake Michigan proper (southern Green Bay > northern Green Bay > northern Lake Michigan). Applying Dobson's et al., (1974) trophic fields, northern Green Bay lies just in the eutrophic field and could be considered meso-eutrophic while southern Green Bay is clearly well in the eutrophic field.

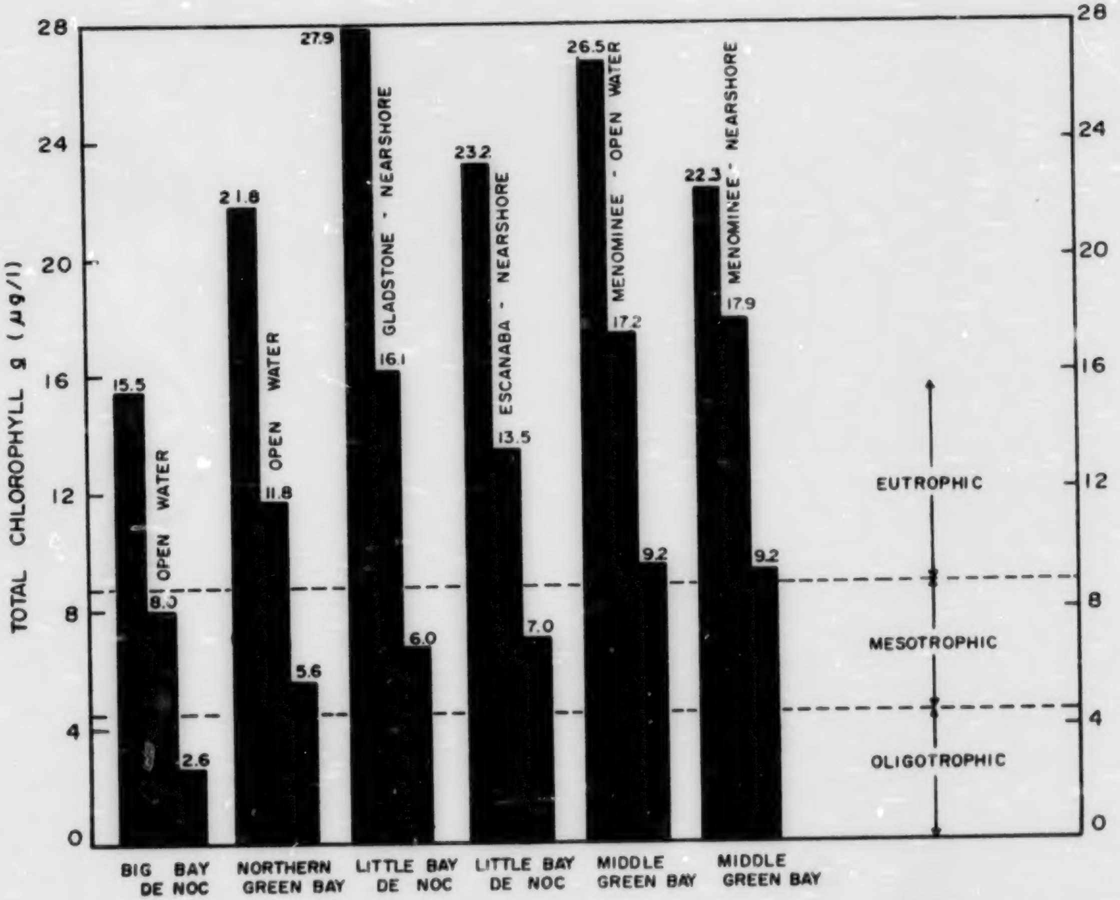

FIGURE C-11. SUMMARY OF CHLOROPHYLL a CONCENTRATIONS IN SURFACE WATERS OF NORTHERN AND MIDDLE GREEN BAY. THE MAXIMUM, MINIMUM AND MEAN VALUES ARE FOR THE ICE-FREE PERIOD (APRIL-OCTOBER) OF 1974. THE TROPHIC RANGE IS FROM DOBSON et. al., (1974).

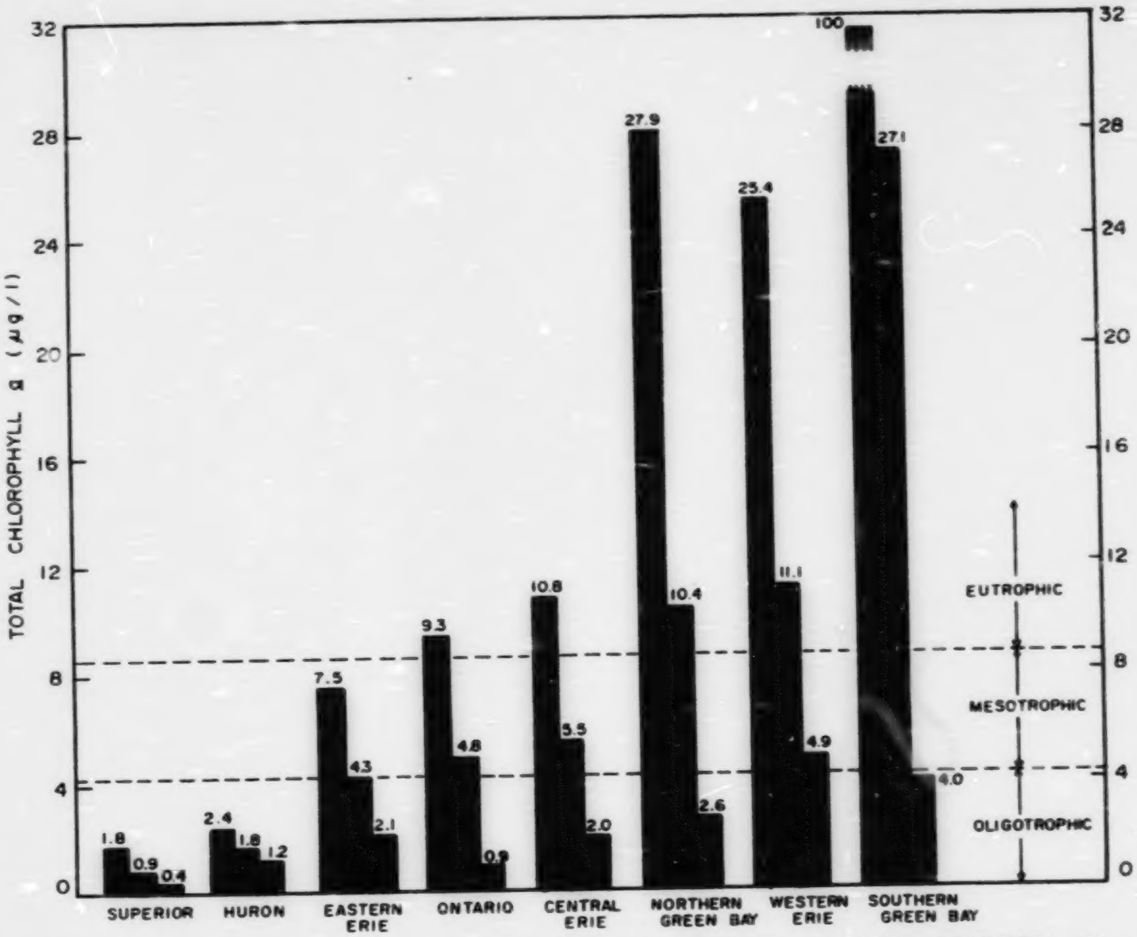

FIGURE C-12. AVERAGE, MAXIMUM AND MINIMUM CHLOROPHYLL a CONCENTRATIONS IN SURFACE WATER OF NORTHERN GREEN BAY (1974) COMPARED WITH OTHER AREAS OF GREAT LAKES. DATA ON GREAT LAKES AND TROPHIC RANGE FROM DOBSON et. al, (1974) SOUTHERN GREEN BAY DATA IS FROM PATTERSON AND EPSTEIN (1975).

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Appendix D

Chemical and nutrient characteristics of northern Green Bay (Lake Michigan) April - October, 1974.

Table D-1. Chemical and nutrient characteristics of northern Green Bay (Lake Michigan). April 24-25, 1974.

Station	Depth (M)	Dissolved oxygen (mg/1)	Temp. (^{o}C)	Percent oxygen saturation	pH	Transparency Secchi disc (M)	Alkal-inity mg/1
Control	1.0	13.6	3.4	106	8.4	4.6	107.2
	6.1	13.7	3.2	106	8.4		107.5
	10.7	13.6	3.2	106	8.3		106.8
Upper Green Bay (OW1)	1.0	14.0	2.2	103	8.5	4.9	106.1
	6.1	13.8	2.3	101	8.7		106.5
	12.2	13.8	2.3	101	8.7		108.5
	15.0	13.8	2.4	101	8.5		108.5
Menominee Offshore (OW2)	1.0	13.5	2.2	99	8.3	3.2	112.5
	6.1	13.5	2.2	99	8.3		112.5
	12.2	13.4	2.2	98	8.3		112.2
	15.0	13.4	2.2	96	8.2		112.6
Gladstone (G)	1.0	12.8	3.0	97	8.2	1.4	79.0
	4.6	13.0	2.8	98	8.1		83.0
	9.1	12.9	2.7	98	8.1		84.4
Escanaba (E)	1.0	13.2	4.4	103	8.2	1.7	86.8
	6.1	13.0	3.8	102	8.3		89.7
	12.2	13.1	3.6	102	8.3		92.5
	15.0	13.1	3.6	102	8.2		96.4
Menominee Nearshore (M)	1.0	12.6	5.5	101	8.3	2.0	97.0
	3.0	12.6	5.5	101	8.2		96.0
	6.1	12.8	5.0	102	8.2		96.0
Portage Marsh #1 (PM1)	1.0	13.2	4.0	103	8.3	0.9*	100.0
Portage Marsh #2 (PM2)	1.0	11.7	5.2	94	8.2	0.8*	89.0

* Total water depth

Table D-1. Continued.

Station	CO_3-Alkalinity (mg/l)	Conductivity (μmho)	Turbidity (mg/l)	Total dissolved solids (mg/l)	Suspended solids (mg/l)	Volatile suspended solids (mg/l)	Color (Pt units)
Control	1.0	226.3	7.0	148	0	0	-
	1.0	230.9	7.0	152	1	0	-
	0.0	232.2	10.5	132	3	1	-
Upper Green Bay (OW1)	0.0	236.4	0.10	162	1	1	18
	0.0	241.2	0.45	160	1	1	20
	0.0	261.6	0.55	162	1	1	-
	0.0	261.6	0.55	140	1	1	20
Menominee Offshore (OW2)	0.0	244.3	8.0	160	4	1	30
	0.0	240.3	7.5	160	5	2	30
	0.0	237.5	7.0	162	4	1	37
	0.0	241.6	7.0	156	4	1	30
Gladstone (G)	0.0	164.2	1.3	175	2	1	50
	0.0	169.6	1.4	150	6	1	50
	0.0	177.9	3.5	152	2	2	47
Escanaba (E)	0.0	185.1	1.15	160	2		37
	0.0	183.0	1.50	128	8		40
	0.0	194.0	1.15	140	2		40
	0.0	215.4	1.40	145	0		47
Menominee Nearshore (M)	0.0	193.7	7.0	140	2	0	50
	0.0	191.8	9.5	150	4	2	50
	0.0	193.2	8.5	144	2	2	-
Portage Marsh #1 (PM1)	0.0	233.8	0.75	182	8	3	20
Portage Marsh #2 (PM2)	0.0	190.9	0.75	182	4	1	30

Table D-1. Continued.

Station	Chlorophyll a (composite) (µg/1)	Pheo-phytin (µg/1)	Nitrate (NO_3-N) (mg/1)	Ammonia (NH_3-N) (mg/1)	Organic nitrogen (mg/1)	Total Phos-phorus (mg/1)	Soluble ortho-phosphate (mg/1)
Control (C)	7.15	0.00	0.235	0.007	0.097	0.010	0.001
			0.253	0.033	0.107	0.014	0.003
			0.203	0.006	0.097	0.017	0.008
Upper Green Bay (OW1)	5.56	0.00	0.183	0.010	0.098	0.005	0.004
			0.176	0.013	0.081	0.010	0.002
			0.160	0.038	0.085	0.004	0.003
			0.176	0.017	0.112	0.013	0.007
Menominee Offshore (OW2)	9.25	0.00	0.130	0.030	0.090	0.016	0.007
			0.180	0.382	0.111	0.016	0.007
			0.185	0.030	0.118	0.015	0.008
			0.149	0.020	0.086	0.007	0.003
Gladstone (G)	7.15	0.00	0.371	0.031	0.082	0.021	0.013
			0.248	0.022	0.172	0.022	0.008
			0.247	0.020	0.188	0.018	0.001
Escanaba (E)	7.94	0.00	0.190	0.024	0.151	0.025	0.002
			0.190	0.030	0.108	0.023	0.004
			0.208	0.019	0.094	0.018	0.004
			0.204	0.014	0.105	0.016	0.003
Menominee Nearshore (M)	9.25	0.00	0.207	0.009	0.133	0.017	0.014
			0.203	0.018	0.165	0.024	0.018
			0.240	0.016	0.151	0.019	0.014
Portage Marsh #1 (PM1)	7.94	0.00	0.014	0.184	0.096	0.014	0.014
Portage Marsh #2 (PM2)	11.56	0.92	0.048	0.136	0.142	0.014	0.048

Table D-1. Continued.

Station	Silica (SiO_2) (mg/1)	Potassium (mg/1)	Sodium (mg/1)	Calcium (mg/1)	Magnesium (mg/1)	Sulfate (mg/1)
Control (C)	0.48	1.09	3.83	31.42	10.62	20.1
	0.50	1.09	3.81	33.63	10.62	18.6
	0.52	1.10	3.93	35.89	10.62	18.5
Upper Green Bay (OW1)	0.54	1.04	3.78	34.13	10.62	19.2
	0.58	1.11	3.82	34.44	10.56	18.9
	0.63	1.10	5.24	34.44	11.04	17.8
	0.67	1.11	3.76	34.75	10.85	18.9
Menominee Offshore (OW2)	0.64	1.17	5.58	34.32	11.51	19.7
	0.71	1.25	5.68	34.63	11.64	20.0
	0.74	1.22	5.39	34.07	11.70	21.4
	0.64	1.17	5.56	34.44	11.74	19.1
Gladstone (G)	1.69	0.76	2.35	24.01	7.94	12.1
	1.64	0.76	2.40	24.58	8.08	11.9
	1.58	0.78	2.52	25.64	8.37	12.6
Escanaba (E)	1.24	1.04	3.72	27.03	8.64	15.4
	1.17	1.00	3.90	27.97	8.85	17.0
	1.30	1.04	3.84	28.79	9.20	16.5
	1.01	1.04	4.26	29.79	9.36	17.2
Menominee Nearshore (M)	1.92	1.04	2.83	28.16	10.64	16.4
	1.95	1.09	2.86	28.16	10.67	17.1
	1.81	1.11	3.28	27.84	10.75	17.1
Portage Marsh #1 (PM1)	1.04	1.05	3.86	29.67	9.84	16.7
Portage Marsh #2 (PM2)	0.68	1.14	5.32	27.03	8.43	19.4

Table D-2. Chemical and nutrient characteristics of northern Green Bay (Lake Michigan). May 29-30, 1974.

Station	Depth (M)	Dissolved oxygen (mg/1)	Temp. (°C)	Percent oxygen saturation	pH	Transparency Secchi disc (M)	Alkal-inity mg/1
Control	1	11.2	12.0	106	8.3	4.5	109.1
	5	11.1	10.8	105	8.3		109.0
	10	11.1	10.7	105	8.3		109.8
	13	11.3	10.2	102	8.2		110.4
Upper Green Bay (OW1)	1	12.1	10.1	109	8.3	4.2	112.0
	5	12.1	9.8	109	8.3		111.6
	10	12.3	9.3	108	8.3		111.2
	15	12.2	8.0	104	8.2		110.5
Menominee Offshore (OW2)	1	12.7	10.5	115	8.3	2.9	113.2
	6	12.6	10.0	114	8.3		114.0
	12	12.8	8.0	109	8.3		114.8
	18	12.4	7.5	104	8.2		116.5
	24	11.7	6.5	93	8.4		115.8
Gladstone (G)	1	11.1	13.5	106	8.2	2.5	93.5
	4	11.0	13.0	105	8.3		92.0
	8	10.9	13.0	105	8.2		92.0
	12	11.0	8.5	96	8.0		104.2
Escanaba (E)	1	11.6	11.0	107	8.3	2.0	105.5
	5	11.6	11.0	107	8.3		105.5
	10	11.6	10.8	106	8.2		106.7
	15	11.4	10.1	103	8.2		106.5
Menominee Nearshore (M)	1	12.6	11.0	117	8.3	2.9	114.3
	3	12.6	10.5	114	8.3		115.8
	6	12.5	10.0	113	8.3		114.5
Portage Marsh #1 (PM1)	1	4.5	15.5	45	7.5	0.8	79.6
Portage Marsh #2 (PM2)	1	11.4	11.3	106	8.4	2.8	113.8
	5	11.6	10.8	107	8.3		111.2
	10	11.6	10.6	106	8.3		110.8

Table D-2. Continued.

Station	CO_3^- Alkalinity (mg/1)	Conductivity (µmho)	Turbidity (mg/1)	Total dissolved solids (mg/1)	Suspended solids (mg/1)	Total volatile solids (mg/1)
Control (C)	1.8	253.5	0.25	138	3.2	2.0
	1.8	255.5	0.45	156	3.6	48.0
	2.0	258.6	0.75	150	4.0	76.8
	1.0	259.6	0.45	204	5.6	86.8
Upper Green Bay (OW1)	3.2	238.0	0.45	162	0.8	32.4
	2.5	267.0	0.25	120	0.8	12.4
	1.8	264.0	0.45	162	1.2	38.4
	1.5	266.6	0.75	156	0.8	28.4
Menominee Offshore (OW2)	2.0	263.6	0.90	178	4.0	66.8
	2.6	264.6	0.75	202	4.8	75.6
	2.2	264.6	0.90	210	4.0	101.2
	2.2	267.7	0.45	182	2.8	66.8
	2.2	266.6	0.90	102	3.2	56.0
Gladstone (G)	0.0	210.1	0.75	76	3.2	24.8
	0.0	211.1	0.45	132	3.6	23.2
	0.0	212.1	1.15	128	4.0	20.0
	0.0	245.0	0.90	78	5.6	7.6
Escanaba (E)	2.8	246.0	0.90	174	1.6	61.2
	1.8	247.9	0.75	182	9.0	68.0
	1.5	247.9	0.75	182	2.4	66.0
	1.5	247.0	0.75	184	0.4	78.0
Menominee Nearshore (M)	2.6	266.6	0.75	174	1.6	30.0
	2.8	265.6	0.75	100	4.4	2.0
	1.5	269.7	0.90	138	3.6	39.6
Portage Marsh #1 (PM1)	0.0	193.9	3.80	124	15.2	45.2
Portage Marsh #2 (PM2)	3.8	262.6		120	0.4	22.4
	3.5	260.6		126	2.0	6.0
	3.0	257.6		142	0.8	18.8

Table D-2. Continued.

Station	Total phosphorus (mg/l)	Soluble ortho-phosphate (mg/l)	Silica (SiO_2) (mg/l)	Color (Pt. Units)	Total organic carbon (mg/l)
Control (C)	0.009	0.005	0.24	28	2.6
	0.008	0.006	0.49	31	
	0.018	0.006	0.18	33	
	0.003	0.002	0.25	38	
Upper Green Bay (OW1)	0.009	0.007	0.17	31	3.3
	0.013	0.012	0.12	20	
	0.014	0.008	0.18	28	
	0.014	0.003	0.23	35	
Menominee Offshore (OW2)	0.031	0.005	0.33	38	4.0
	0.039	0.013	0.27	50	
	0.007	0.006	0.29	49	
	0.005	0.004	0.28	32	
	0.004	0.001	0.38	53	
Gladstone (C)	0.017	0.007	0.77	51	7.3
	0.015	0.008	0.49	67	
	0.017	0.008	0.87	68	
	0.019	0.006	0.62	60	
Escanaba (E)	0.005	0.001	0.26	38	4.5
	0.005	0.004	0.24	33	
	0.005	0.002	0.20	30	
	0.016	0.012	0.13	30	
Menominee Nearshore (M)	0.014	0.012	0.87	50	3.8
	0.016	0.009	0.30	47	
	0.017	0.013	0.35	32	
Portage Marsh #1 (PM1)	0.194	0.131	0.38	150	14.6
Portage Marsh #2 (PM2)	0.009	0.008	0.13	30	3.8
	0.012	0.006	0.19	30	
	0.014	0.009	0.20	29	

Table D-2. Continued.

Station	Color (Pt. Units)	Chlorophyll *a* composite (g/1)	Pheophytin (g/1)	Nitrate (NO_3-N) (mg/1)	Ammonia (NH_3-N) (mg/1)	Organic nitrogen (mg/1)	Total phosphorus (mg/1)
Control (C)	28	15.48	0.00	0.117	0.022	0.367	0.009
	31			0.116	0.014	0.341	0.008
	33			0.124	0.018	0.287	0.018
	38			0.130	0.017	0.300	0.003
Upper Green Bay (OW1)	31	21.77	1.07	0.125	0.016	0.170	0.009
	20			0.132	0.017	0.317	0.013
	28			0.132	0.028	0.114	0.014
	35			0.158	0.024	0.159	0.014
Menominee Offshore (OW2)	38	19.81	0.00	0.080	0.014	0.427	0.031
	50			0.080	0.017	0.458	0.039
	49			0.118	0.014	0.457	0.007
	32			0.120	0.012	0.393	0.005
	53			0.147	0.016	0.508	0.004
Gladstone (C)	51	19.00	5.60	0.113	0.016	0.324	0.017
	67			0.114	0.014	0.335	0.015
	68			0.112	0.039	0.222	0.017
	60			0.148	0.022	0.300	0.019
Escanaba (E)	38	23.20	23.20	0.117	0.072	0.328	0.005
	33			0.113	0.061	0.286	0.005
	30			0.121	0.020	0.402	0.005
	30			0.020	0.017	0.402	0.016
Menominee Nearshore (M)	50	22.14	20.47	0.087	0.027	0.391	0.014
	47			0.087	0.018	1.065	0.016
	32			0.086	0.012	0.352	0.017
Portage Marsh #1 (PM1)	150	96.24	0.00	0.118	0.024	0.460	0.194
Portage Marsh #2 (PM2)	30	13.07	6.26	0.103	0.020	0.157	0.009
	30			0.117	0.012	0.837	0.012
	29			0.121	0.028	0.244	0.014

Table D-2. Continued.

Station	Soluble ortho-phosphate (mg/1)	Silica (SiO_2) (mg/1)	Total organic carbon (mg/1)
Control (C)	0.005	0.24	2.6
	0.006	0.49	
	0.006	0.18	
	0.002	0.25	
Upper Green Bay (OW1)	0.007	0.17	3.3
	0.012	0.12	
	0.008	0.18	
	0.003	0.23	
Menominee Offshore (OW2)	0.005	0.33	4.0
	0.013	0.27	
	0.006	0.29	
	0.004	0.28	
	0.001	0.38	
Gladstone (C)	0.007	0.77	7.3
	0.008	0.49	
	0.008	0.87	
	0.006	0.62	
Escanaba (E)	0.001	0.26	4.5
	0.004	0.24	
	0.002	0.20	
	0.012	0.13	
Menominee Nearshore (M)	0.012	0.87	3.8
	0.009	0.30	
	0.013	0.35	
Portage Marsh #1 (PM1)	0.131	0.38	14.6
Portage Marsh #2 (PM2)	0.008	0.13	3.8
	0.006	0.19	
	0.009	0.20	

Table D-3. Chemical and nutrient characteristics of northern Green Bay (Lake Michigan). July 27-28, 1974.

Station	Depth (M)	Dissolved oxygen (mg/1)	Temp. (°C)	Percent oxygen saturation	pH	Transparency Secchi disc (M)	Alkal-inity (mg/1)
Control (C)	1	8.9	20.0	97	8.5	5.5	108.0
	6	8.9	20.0	97	8.6		109.0
	12	8.7	19.0	93	8.6		108.0
Upper Green Bay (OW1)	1	8.8	20.0	97	8.6	3.5	109.0
	9	9.0	19.5	98	8.5		115.0
	11	9.4	15.5	94	8.4		109.0
	14	9.4	12.5	87	8.4		109.0
	16	9.0	11.5	82	8.6		110.0
Menominee Offshore (OW2)	1	8.7	17.0	83	8.3	2.8	114.0
	5	8.2	17.0	88	8.3		114.0
	8	7.5	12.5	79	8.0		112.0
	15	9.4	9.0	81	8.0		112.0
	24	8.1	7.5	77	7.9		110.0
Gladstone (G)	1	9.9	21.5	110	8.6	-	109.0
	11	8.9	20.5	100	8.3		111.0
	12	7.2	13.5	78	8.1		110.0
	14	6.7	13.0	62	8.5		109.5
Escanaba (E)	1	8.9	20.3	97	8.5	3.8	108.0
	9	8.9	20.0	97	8.4		108.5
	11	9.2	15.0	90	8.1		109.5
	13	8.0	12.0	78	8.1		110.0
	18	7.7	9.0	66	8.0		112.0
Menominee Nearshore (M)	1	9.1	21.0	83	8.3	4.2	112.0
	3	9.1	11.5	83	8.0		112.0
	6	8.0	10.0	70	8.0		111.0
Portage Marsh #1 (PM1)	1	6.5	21.0	73	8.1	Total depth	111.0
Portage Marsh #2 (PM2)	1	9.1	19.5	97	8.3	3.8	109.0
	2	8.4	18.5	87	8.1		111.0
	3	6.7	15.5	76	8.1		110.0

Table D-3. Continued.

Station	CO_3-Alkalinity (mg/1)	Conductivity (µmho)	Turbidity (mg/1)	Total dissolved solids (mg/1)	Suspended solids (mg/1)	Total volatile solids (mg/1)	Color (Pt-Units)	Chlorophyll a composite (µg/1)
Control	5.5	238	1.1	158	0.0	2	30	4.88
	4.5	238	1.1	156	0.0	30	30	
	5.0	238	1.8	166	0.4	50	25	
Upper Green Bay (OW1)	4.0	246	0.5	127	1.2	32	9	8.14
	0.0	262	0.5	148	0.0	40	7	
	3.0	250	0.4	152	0.0	42	10	
	2.5	241	0.6	128	0.0	70	15	
	3.0	238	0.7	160	0.4	58	18	
Menominee Offshore (OW2)	3.0	246	1.8	246	4.4	68	30	16.47
	0.0	252	1.4	308	3.2	106	30	
	0.0	248	1.0	264	3.2	50	28	
	0.0	247	-	310	0.8	64	20	
	0.0	249	1.1	280	14.0	57	30	
Gladstone (G)	0.0	241	1.1	258	4.0	57	25	6.82
	2.0	240	2.3	272	4.4	53	35	
	0.0	262	1.5	264	4.0	58	30	
	2.0	252	1.8	228	5.2	50	30	
Escanaba (E)	2.5	237	1.5	158	4.0	48	20	6.97
	1.0	240	1.4	196	4.8	54	30	
	0.0	242	1.0	206	4.8	48	30	
	0.0	248	0.5	198	4.4	54	20	
	0.0	248	0.9	190	2.0	56	35	
Menominee Nearshore (M)	0.0	247	0.7	176	0.8	92	20	15.34
	0.0	248	1.5	166	0.8	96	30	
	0.0	247	1.1	166	2.4	84	40	
Portage Marsh #1 (PM1)	0.0	233	1.0	178	0.8	62	50	9.30
Portage Marsh #2 (PM2)	3.0	238	1.2	168	0.4	82	18	5.35
	0.0	246	1.1	190	0.8	64	23	
	0.0	242	1.2	188	4.8	48	26	

Table D-3. Continued.

Station	Pheo-phytin (µg/1)	Nitrate (NO_3-N) (mg/1)	Ammonia (NH_3-N) (mg/1)	Organic nitrogen (mg/1)	Total Phos-phorus (mg/1)	Soluble ortho-phosphate (mg/1)	Silica (SiO_2) (mg/1)	Chloride (mg/1)
Control (C)	-1.92	0.151	0.016	0.191	0.001	0.000	0.24	9.0
		0.106	0.011	0.259	0.000	0.000	0.32	7.4
		0.101	0.028	0.224	0.000	0.000	0.34	8.5
Upper Green Bay (OW1)	-2.28	0.084	0.021	0.222	0.004	0.001	0.14	11.3
		0.089	0.020	0.422	0.028	0.005	0.14	8.5
		0.140	0.024	0.165	0.006	0.001	0.11	11.8
		0.137	0.027	1.071	0.001	0.001	0.18	9.4
		0.088	0.015	0.171	0.000	0.000	0.14	10.8
Menominee Offshore (OW2)	-8.10	0.074	0.009	0.331	0.019	0.002	0.29	9.0
		0.090	0.008	0.168	0.020	0.003	0.25	10.3
		0.144	0.018	0.147	0.010	0.005	0.29	10.8
		0.199	0.038	0.137	0.009	0.007	0.55	9.4
		0.215	0.035	0.654	0.006	0.005	0.78	8.5
Gladstone (G)	-0.12	0.084	0.040	0.636	0.029	0.018	0.27	9.4
		0.093	0.053	0.717	0.027	0.005	0.41	9.4
		0.117	0.072	0.106	0.024	0.007	0.63	9.4
		0.090	0.058	0.175	0.019	0.002	0.29	9.0
Escanaba (E)	-1.39	0.084	0.030	1.048	0.002	0.000	0.25	13.0
		0.089	0.036	0.370	0.000	0.000	0.30	13.6
		0.141	0.044	0.488	0.000	0.000	0.22	8.2
		0.144	0.065	0.237	0.012	0.007	0.49	7.8
		0.166	0.084	0.319	0.014	0.010	0.59	9.4
Menominee Nearshore (M)	-6.30	0.192	0.035	0.407	0.013	0.010	0.85	10.3
		0.160	0.056	0.245	0.010	0.009	0.79	9.8
		0.181	0.016	0.172	0.015	0.011	0.88	8.5
Portage Marsh #1 (PM1)	1.30	0.068	0.018	0.324	0.134	0.077	0.24	9.8
			0.025	0.888	0.009	0.007	0.21	11.8
Portage Marsh #2 (PM2)	-1.16	0.101	0.243	0.314	0.066	0.036	0.41	11.3
		0.126	0.107	0.235	0.020	0.001	0.64	12.4
		0.274						

Table D-4. Chemical and nutrient characteristics of northern Green Bay (Lake Michigan). Sept. 28-29, 1974.

Station	Depth (M)	Dissolved oxygen (mg/1)	Temp. (^oC)	Percent oxygen saturation	pH	Transparency Secchi disc (M)	Alkalinity (mg/1)
Control	1	9.6	17.5	100	8.3	4.0	112.9
	5	9.6	17.5	100	8.3		113.0
	10	9.6	17.5	100	8.3		112.1
	13	9.6	17.5	100	8.3		112.1
Upper Green Bay (OW1)	1	9.5	16.5	96	8.4	3.5	113.3
	5	9.9	16.5	100	8.4		113.2
	10	9.9	16.5	100	8.4		113.5
	15	9.8	16.5	99	8.4		113.2
Menominee Offshore (OW2)	1	9.8	16.0	98	8.4	2.3	114.5
	10	9.2	15.5	93	8.2		113.0
	12	7.4	12.0	78	8.0		114.0
	16	7.6	10.0	76	7.8		113.0
	22	7.0	9.5	61	7.8		113.8
Gladstone (G)	1	9.3	17.0	95	8.4	2.4	112.5
	6	9.2	17.0	95	8.4		114.1
	12	8.4	17.0	85	8.2		114.0
Escanaba (E)	1	10.0	17.0	102	8.4	2.0	112.2
	6	9.8	17.0	100	8.4		113.2
	12	9.8	17.0	100	8.3		113.8
	18	9.7	16.5	97	8.1		114.0
Menominee Nearshore (M)	1	9.6	15.0	94	8.3	2.2	116.0
	3	9.7	15.0	95	8.4		116.0
	6	9.7	15.0	95	8.3		115.5
Portage Marsh #1 (PM1)	1	8.4	18.0	87	7.9	Total	113.3
Portage Marsh #2 (PM2)	1	9.7	17.0	98	8.3	2.3	114.4
	6	9.7	17.0	98	8.3		114.0
	12	9.5	17.0	96	8.3		111.5

Table D-4. Continued.

Station	CO_3- Alkalinity (mg/1)	Conductivity (μmho)	Turbidity (mg/1)	Total dissolved solids (mg/1)	Suspended solids (mg/1)	Total volatile solids (mg/1)	Color (Pt-units)	Chlorophyll *a* composite (μg/1)
Control	3.0	266	2.7	12	2.0	42	22	2.56
	3.0	269	2.3	78	1.6	18	22	
	3.2	268	2.3	46	2.0	16	20	
	3.1	266	1.6	46	1.6	40	15	
Upper Green	4.2	271	0.4	96	1.6	8	10	8.37
Bay	3.2	271	0.8	118	1.6	4	10	
(OW1)	4.2	269	0.9	82	1.6	28	25	
	3.0	271	0.9	102	3.2	36	30	
Menominee	3.1	271	1.4	112	2.0	36	20	13.95
Offshore	1.0	275	2.3	76	2.4	18	23	
(OW2)	0.0	272	0.8	108	0.8	8	15	
	0.0	272	0.9	174	2.8	44	10	
	0.0	272	4.8	158	14.8	39	20	
Gladstone	3.0	263	1.0	174	4.0	38	21	27.90
(G)	3.0	265	1.4	168	4.4	30	20	
	2.1	264	1.6	170	6.8	66	40	
Escanaba	4.4	269	1.6	80	4.4	68	40	11.93
(E)	5.0	270	1.4	112	3.2	18	33	
	3.7	272	1.6	164	4.0	16	13	
	2.0	272	1.6	116	7.2	12	13	
Menominee	3.5	265	3.5	166	3.6	48	23	20.46
Nearshore	3.0	268	5.8	174	3.6	34	21	
(M)	2.2	268	5.1	106	3.2	68	20	
Portage Marsh #1 (PM1)	0.0	248	2.9	72	10.4	26	83	12.55
Portage Marsh	2.3	274	1.4	22	1.2	20	38	23.71
#2 (PM2)	2.8	265	2.1	130	0.0	20	30	
	2.2	270	1.4	118	2.4	2	40	

Table D-4. Continued.

Station	Pheo-phytin ($\mu g/l$)	Nitrate (NO_3-N) (mg/l)	Ammonia (NH_3-N) (mg/l)	Organic nitrogen (mg/l)	Total phosphorus (mg/l)	Soluble ortho-phosphate (mg/l)	Silica (SiO_2) (mg/l)
Control (C)	0.00	0.094	0.037	0.243	*	0.000	0.45
		0.098	0.023	0.257	0.000	0.000	0.41
		0.087	0.016	0.258	0.006	0.000	0.50
		0.086	0.026	0.319	0.000	0.000	0.50
Upper Green Bay (OW1)	0.00	0.087	0.822	0.011	0.000	0.000	0.30
		0.096	0.037	0.025	0.000	0.000	0.32
		0.092	0.011	0.064	0.000	0.000	0.36
		0.085	0.030	*	0.000	0.000	0.36
Menominee Offshore (OW2)	0.00	0.057	0.012	0.142	0.006	0.000	0.54
		0.112	0.031	0.256	0.006	0.000	0.57
		0.195	0.032	0.192	0.004	0.000	0.55
		0.201	0.009	0.165	0.015	0.000	0.80
		0.195	0.007	0.167	0.032	0.000	0.88
Gladstone (G)	0.00	0.056	0.052	0.304	0.023	0.003	0.43
		0.056	0.014	0.210	*	0.002	0.45
		0.062	0.032	0.361	0.027	0.003	0.58
Escanaba (E)	0.00	0.061	0.018	0.297	0.007	0.000	0.39
		0.056	0.020	0.390	0.004	0.000	0.43
		0.061	0.025	0.309	0.003	0.000	0.45
		0.069	0.045	0.319	0.011	0.000	0.59
Menominee Nearshore (M)	0.00	0.071	0.012	0.336	0.027	0.004	0.81
		0.081	0.020	0.308	0.011	0.002	0.80
		0.090	0.009	0.299	0.010	0.000	0.79
Portage Marsh #1 (PM1)	0.50	0.083	0.014	0.540	0.035	0.107	0.27
Portage Marsh #2 (PM2)	0.00	0.077	0.022	0.420	0.046	0.018	0.45
		0.077	0.028	0.190	0.016	0.000	0.38
		0.070	0.022	0.132	0.022	0.006	0.46

* Sample contaminated by laboratory.

Table D-5. Chemical and nutrient characteristics of northern Green Bay (Lake Michigan). October 26-27, 1974.

Station	Depth (M)	Dissolved (mg/1)	Temp. (^oC)	Percent oxygen saturation	pH	Transparency Secchi disc (M)	Alkal-inity (mg/1)	CO_3-Al-kalinity (mg/1)
Control	1	11.6	8.0	98	8.4	2.6	111.9	3.8
	6	11.8	8.0	99	8.5		112.0	3.1
	13	12.2	8.0	102	8.5		111.8	1.4
Upper Green Bay (OW1)	1	12.0	8.5	101	8.4	3.4	114.0	5.0
	5	13.0	8.5	110	8.4		113.8	2.2
	10	13.2	8.0	112	8.4		113.0	2.2
	15	13.2	8.0	112	8.4		112.0	1.4
Menominee Offshore (OW2)	1	12.8	9.0	109	8.2	2.2	115.5	2.2
	8	12.4	9.0	103	8.2		115.5	1.0
	18	11.2	9.0	96	8.2		115.5	1.0
	23	8.0	9.0	78	8.3		116.0	1.6
Gladstone (G)	1	11.2	10.0	98	8.2	2.0	113.0	4.0
	6	11.6	10.0	101	8.2		114.0	2.2
	13	12.2	10.0	107	8.2		114.0	0.0
Escanaba (E)	1	12.3	8.0	103	8.4	2.8	112.0	2.0
	6	12.4	8.0	104	8.4		117.0	1.5
	12	12.2	8.0	103	8.3		117.0	1.0
	18	12.4	8.0	104	8.3		146.0	2.0
Menominee Nearshore (M)	1	14.0	9.0	120	8.3	2.8	117.0	2.0
	3	13.8	8.5	117	8.3		114.5	1.3
	6	14.2	8.5	121	8.2		114.9	0.1
Portage Marsh #1 (PM1)	1	13.4	8.0	112	8.1	1.0	118.3	0.0
Portage Marsh #2 (PM2)	1	13.0	8.5	109	8.2	2.5	113.2	2.0
	5	12.8	8.0	108	8.2		113.5	1.8
	10	13.4	8.0	112	8.3		113.2	1.9

Table D-5. Continued.

Station	Conductivity (µmho)	Turbidity (mg/1)	Total dissolved solids (mg/1)	Suspended solids (mg/1)	Total volatile solids (mg/1)	Color (Pt-units)	Chlorophyll $\underline{a}$ composite (µg/1)	Pheophytin (µg/1)
Control	268.5	3.5	168	3.2	30	0	10.07	0.00
	270.7	3.5	130	3.2	34	0		
	269.7	2.4	126	4.4	42	0		
Upper Green Bay (OW1)	375.7	2.9	150	3.6	30	0	15.34	0.00
	272.8	1.6	124	0.0	52	0		
	283.0	4.4	138	2.8	24	0		
	283.2	5.3	158	4.4	28	0		
Menominee Offshore (OW2)	273.2	1.9	164	3.6	46	0	26.50	0.00
	280.0	5.9	170	2.0	88	0		
	280.0	4.1	128	1.6	58	0		
	280.0	3.1	146	3.2	78	0		
Gladstone (G)	259.0	9.0	76	2.4	76	0	19.53	0.00
	229.4	2.9	60	0.6	60	12		
	258.4	7.2	68	23.2	68	30		
Escanaba (E)	272.8	0.7	172	5.6	72	0	17.43	0.00
	273.8	1.1	172	1.6	56	0		
	276.9	1.4	180	3.6	58	0		
	276.9	1.6	176	4.4	60	15		
Menominee Nearshore (M)	254.0	4.1	172	1.2	44	0	22.32	0.00
	252.0	4.1	152	2.4	42	0		
	246.8	4.1	152	4.3	52	0		
Portage Marsh #1 (PM1)	271.4	2.4	182	6.8	56	40	29.29	0.00
Portage Marsh #2 (PM2)	275.4	1.9	140	4.0	30	0	19.53	0.00
	274.4	1.9	144	3.2	44	0		
	270.8	0.7	156	2.4	54	0		

Table D-5. Continued.

Station	Nitrate (NO_3-N) (mg/1)	Ammonia (NH_3-N) (mg/1)	Organic nitrogen (mg/1)	Total phosphorus (mg/1)	Soluble ortho-phosphate (mg/1)	Silica (SiO_2) (mg/1)	Total Organic carbon (mg/1)
Control (C)	0.033	0.044	0.043	0.018	**	0.39	4
	0.036	0.017	0.045	0.012	0.005	0.40	
	0.033	0.035	0.006	0.009	0.018	0.41	3
Upper Green Bay (OW1)	0.074	0.063	0.059	0.007	0.008	0.71	4
	0.074	0.045	0.013	0.034	0.024	0.68	
	0.069	0.024	0.027	0.009	0.003	0.67	
	0.071	0.023	0.040	0.211	0.074	0.67	4
Menominee Offshore (OW2)	0.026	0.014	0.025	0.047	0.022	0.93	3
	0.028	0.014	0.030	0.038	0.016	0.90	
	0.026	0.019	0.077	0.020	0.012	0.91	
	0.025	0.017	0.151	0.046	0.008	0.93	3
Gladstone (G)	0.015	0.011	0.151	0.036	0.016	0.42	5
	0.007	0.002	0.119	0.073	0.018	0.37	
	0.010	0.004	0.028	0.132	0.011	0.43	7
Escanaba (E)	0.058	0.022	0.116	0.019	0.015	0.66	4
	0.058	0.026	0.131	0.025	0.025	0.59	
	0.062	0.020	0.128	0.039	0.014	0.61	
	0.064	0.020	0.402	0.024	0.011	0.62	4
Menominee Nearshore (M)	0.019	0.016	0.089	0.028	0.016	1.09	4
	0.017	0.018	0.202	0.028	0.007	1.08	
	0.018	0.022	0.097	0.038	0.007	1.38	5
Portage Marsh #1 (PM1)	0.020	0.012	0.226	0.050	0.017	0.59	8
Portage Marsh #2 (PM2)	0.065	0.023	0.007	0.068	0.008	0.66	4
	0.064	0.024	0.014	0.044	0.025	0.66	3
	0.066	0.027	0.010	0.028	0.017	0.66	4

** Sample contaminated by laboratory.

Appendix E

Phytoplankton of Northern Green Bay (Lake Michigan)

Phytoplankton of Northern Green Bay (Lake Michigan)

Little documentation is available on the phytoplankton assemblages in northern Green Bay. Reported studies on this embayment of Lake Michigan are mainly from southern Green Bay (Holland 1969 and 1975, Sager 1971, and Patterson and Epstein, 1975). This section deals with the phytoplankton species composition, numerical abundance and spatial and seasonal distribution in northern Green Bay. When possible, data are compared to other Great Lakes and embayments to provide a clearer impression of the relative position of primary production in this water mass. Additionally, the presence of algal species associated with taste and odor nuisances (earthy-musty odor) in municipal water supplies and their contributive role were assessed.

MATERIALS AND METHODS

Five surveys were conducted (April, May, July, September and October) at eight stations in northern Green Bay (Lake Michigan). Composite water samples from Green Bay were collected for chlorophyll a and algal analysis and obtained through a depth twice that of transparency measurement. Phytoplankton samples were field-preserved in glutaraldehyde, filtered into 0.80 μ "AA" millipore filters, and semi-permanent slides were prepared by clearing the filters with beechwood creasote. Identification and enumeration was accomplished with a Leitz Ortholux microscope fitted with a fluorite oil immersion objective. This provided a magnification of 1250 x and a numerical aperture of 1.32 (Stoermer et al., 1971; Stoermer, personal communication, 1974). Population estimation was achieved on basis of two 10 mm radial strips and converted to a frequency per volume basis. Values represent individual cells except for certain blue-green forms. Diversity was measured by the Shannon-Wierner (Stockman and Benson, 1967) information index (Stoermer, personal communication, 1974).

RESULTS - CONCLUSIONS

Phytoplankton Standing Crop (cell number)

Highest algal densities (excluding Portage Marsh) occurred on October 26-27 (Tables E-1, to E-8, Figure E-1). There was a spring maximum in May (1987 cells/ml), decline in July (267 cells/ml) followed by a fall maximum (2146 cells/ml). The highest standing crop (4296 cells/ml) was in Portage Marsh on October 26-27 (Table E-7).

Phytoplankton Species Composition

Figures E-1, E-2, and E-3 show the station and seasonal variation (percentage) in major phytoplankton taxa throughout northern Green Bay.

Table E-1. Cell counts (cells/ml) and percent abundance of algal taxa in Big Bay de Noc (Lake Michigan) in 1974.

Big Bay de Noc	24-25 April		29-30 May		28-30 July		7-8 September		26-27 October	
	cells	percent[1]	cells	percent	cells	percent	cells	percent	cells	percent
Bacillariophyta (diatoms)	1351	78.5	1221	92.5	79	35.4	453	39.9	2304	89.8
Cyanophyta (blue-green algae)	318	18.5	2	0.2	101	45.3	413	36.3	174	6.8
Chlorophyta (green algae)	25	1.5	80	6.0	43	19.3	269	23.6	69	2.7
Chrysophyta (chrysophytes)	17	1.0	0	0.0	0	0.0	0	0.0	2	0.1
Cryptophyta (cryptomonads)	2	0.1	0	0.0	0	0.0	0	0.0	0	0.0
Pyrrophyta (dinoflagellates)	0	0.0	0	0.0	0	0.0	0	0.0	2	0.1
Total number of taxa	57		32		17		33		40	
Total cells/ml	1722		1320		222		1137		2564	
Diversity	2.6		2.3		2.3		2.1		1.7	

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[1] Percent does not always total 100 as certain stations on a specific date contained unidentified algae and taxonomic units other than listed here.

Table E-2. Cell counts (cells/ml) and percent abundance of algal taxa in Upper Green Bay (Lake Michigan) in 1974.

Upper Green Bay (OW1)	24-25 April		29-30 May		28-30 July		7-8 September		26-27 October	
	cells	percent[1]	cells	percent	cells	percent	cells	percent	cells	percent
Bacillariophyta (diatoms)	1106	97.4	1625	92.8	128	77.7	102	15.1	1462	67.6
Cyanophyta (blue-green algae)	19	1.7	15	0.8	0	0.0	535	79.3	597	27.6
Chlorophyta (green algae)	11	0.9	61	3.5	37	22.3	37	5.4	103	4.8
Chrysophyta (chrysophytes)	0	0.0	13	0.7	0	0.0	1	0.2	0	0.0
Cryptophyta (cryptomonads)	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Pyrrophyta (dinoflagellates)	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total number of taxa	37		38		14		24		36	
Total cells/ml	1135		1751		164		674		2161	
Diversity	2.2		2.4		1.7		1.7		2.2	

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[1] Percent does not always total 100 as certain stations on a specific date contained unidentified algae and taxonomic units other than listed here.

Table E-3. Cell counts (cells/ml) and percent abundance of algal taxa near Escanaba (Lake Michigan) in 1974.

Escanaba (E)	24-25 April		29-30 May		28-30 July		7-8 September		26-27 October	
	cells	percent[1]	cells	percent	cells	percent	cells	percent	cells	percent
Bacillariophyta (diatoms)	1405	99.9	1449	94.1	110	34.9	1162	89.4	1554	83.4
Cyanophyta (blue-green algae)	0	0.0	27	1.8	161	51.2	47	3.6	235	12.6
Chlorophyta (green algae)	0	0.0	63	4.1	41	12.9	81	6.2	75	4.0
Chrysophyta (chrysophytes)	2	0.1	0	0.0	2	0.7	3	0.2	0	0.0
Cryptophyta (cryptomonads)	0	0.0	0	0.0	1	0.3	0	0.0	0	0.0
Pyrrophyta (dinoflagellates)	0	0.0	0	0.0	0	0.0	2	0.2	0	0.0
Total number of taxa	63		32		24		48		35	
Total cells/ml	1407		1539		315		1301		1864	
Diversity	2.1		2.4		1.9		2.2		2.5	

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[1] Percent does not always total 100 as certain stations on a specific date contained unidentified algae and taxonomic units other than listed here.

Table E-4. Cell counts (cells/ml) and percent abundance of algal taxa near Gladstone (Lake Michigan) in 1974.

Gladstone (G)	24-25 April		29-30 May		28-30 July		7-8 September		26-27 October	
	cells	percent[1]	cells	percent	cells	percent	cells	percent	cells	percent
Bacillariophyta (diatoms)	551	98.5	1575	95.9	227	78.3	707	86.0	1799	81.4
Cyanophyta (blue-green algae)	2	0.4	40	2.4	36	12.3	33	3.9	228	10.3
Chlorophyta (green algae)	0	0.0	8	0.5	17	5.8	81	9.8	182	8.2
Chrysophyta (chrysophytes)	6	1.1	4	0.3	0	0.0	2	0.3	0	0.0
Cryptophyta (cryptomonads)	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Pyrrophyta (dinoflagellates)	0	0.0	2	0.1	0	0.0	0	0.0	2	0.1
Total number of taxa	64		42		18		43		37	
Total cells/ml	559		1642		290		822		2212	
Diversity	3.6		2.7		1.8		2.6		2.5	

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[1] Percent does not always total 100 as certain stations on a specific date contained unidentified algae and taxonomic units other than listed here.

Table E-5. Cell counts (cells/ml) and percent abundance of algal taxa near Menominee (nearshore) (Lake Michigan) in 1974.

Menominee-nearshore (M)	24-25 April		29-30 May		28-30 July		7-8 September		26-27 October	
	cells	percent[1]	cells	percent	cells	percent	cells	percent	cells	percent
Bacillariophyta (diatoms)	1347	97.3	1977	93.9	60	34.1	289	33.3	1443	64.6
Cyanophyta (blue-green algae)	27	2.0	86	4.1	35	19.8	517	59.6	674	30.2
Chlorophyta (green algae)	8	0.6	31	1.5	78	44.3	58	6.6	117	5.2
Chrysophyta (chrysophytes)	0	0.0	8	0.4	0	0.0	0	0.0	0	0.0
Cryptophyta (cryptomonads)	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Pyrrophyta (dinoflagellates)	0	0.0	0	0.0	1	0.6	0	0.0	0	0.0
Total number of taxa	63		39		20		26		31	
Total cells/ml	1384		2105		175		868		2235	
Diversity	2.6		2.5		2.4		1.9		2.3	

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[1] Percent does not always total 100 as certain stations on a specific date contained unidentified algae and taxonomic units other than listed here.

Table E-6. Cell counts (cells/ml) and percent abundance of algal taxa in middle Green Bay (Lake Michigan) in 1974.

Middle Green Bay (Menominee offshore)	24-25 April		29-30 May		28-30 July		7-8 September		26-27 October	
	cells	percent[1]	cells	percent	cells	percent	cells	percent	cells	percent
Bacillariophyta (diatoms)	1451	80.1	1676	92.9	44	10.1	237	24.9	798	43.2
Cyanophyta (blue-green algae)	115	6.4	84	4.7	310	71.0	433	45.4	769	41.7
Chlorophyta (green algae)	230	12.7	36	2.0	82	18.7	282	29.6	274	14.9
Chrysophyta (chrysophytes)	2	0.1	4	0.2	1	0.2	0	0.0	0	0.0
Cryptophyta (cryptomonads)	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Pyrrophyta (dinoflagellates)	2.2	0.1	4	0.2	0	0.0	1	0.1	0	0.0
Total number of taxa	36		38		17		22		28	
Total cells/ml	1812		1803		437		952		1845	
Diversity	2.5		2.5		2.0		1.9		2.1	

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[1] Percent does not always total 100 as certain stations on a specific date contained unidentified algae and taxonomic units other than listed here.

Table E-7. Cells counts (cells/ml) and percent abundance of algal taxa in northern Green Bay (Lake Michigan) in 1974.

Portage Marsh (PM1)	24-25 April		29-30 May		28-30- July		7-8 September		26-27 October	
	cells	percent[1]	cells	percent	cells	percent	cells	percent	cells	percent
Bacillariophyta (diatoms)	961	98.1	2076	90.7	319	75.1	1207	99.1	4124	96.0
Cyanophyta (blue-green algae)	11	1.1	67	2.9	1	0.2	5	0.4	119	2.8
Chlorophyta (green algae)	4	0.4	130	5.7	98	23.2	4	0.4	19	0.4
Chrysophyta (chrysophytes)	0	0.0	11	0.5	2	0.5	1	0.1	19	0.4
Cryptophyta (cryptomonads)	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Pyrrophyta (dinoflagellates)	0	0.4	4	0.2	0	0.0	0	0.0	6	0.2
Total number of taxa	56		70		56		59		60	
Total cells/ml	980		2287		425		1218		4296	
Diversity	2.8		3.3		3.0		2.8		2.2	

[1] Percent does not always total 100 as certain stations on a specific date contained unidentified algae and taxonomic units other than listed here.

Table E-8. Cell counts (cells/ml) and percent abundance of algal taxa in northern Green Bay (Lake Michigan) in 1974.

Portage Marsh (PM2)	24-25 April		29-30 May		28-30 July		7-8 September		26-27 October	
	cells	percent[1]	cells	percent	cells	percent	cells	percent	cells	percent
Bacillariophyta (diatoms)	1449	89.6	1397	87.9	263	77.7	650	82.2	1801	80.5
Cyanophyta (blue-green algae)	6	0.4	8	0.6	1	0.3	104	13.1	388	17.3
Chlorophyta (green algae)	157	9.7	180	11.3	73	21.7	34	4.2	48	2.2
Chrysophyta (chrysophytes)	4	0.3	2	0.1	1	0.3	4	0.5	0	0.0
Cryptophyta (cryptomonads)	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Pyrrophyta (dinoflagellates)	0	0.0	2	0.1	0	0.0	0	0.0	0	0.0
Total number of taxa	83		52		28		36		33	
Total cells/ml	1617		1590		338		792		2237	
Diversity	3.5		2.6		2.4		2.4		2.2	

[1] Percent does not always total 100 as certain stations on a specific date contained unidentified algae and taxonomic units other than listed here.

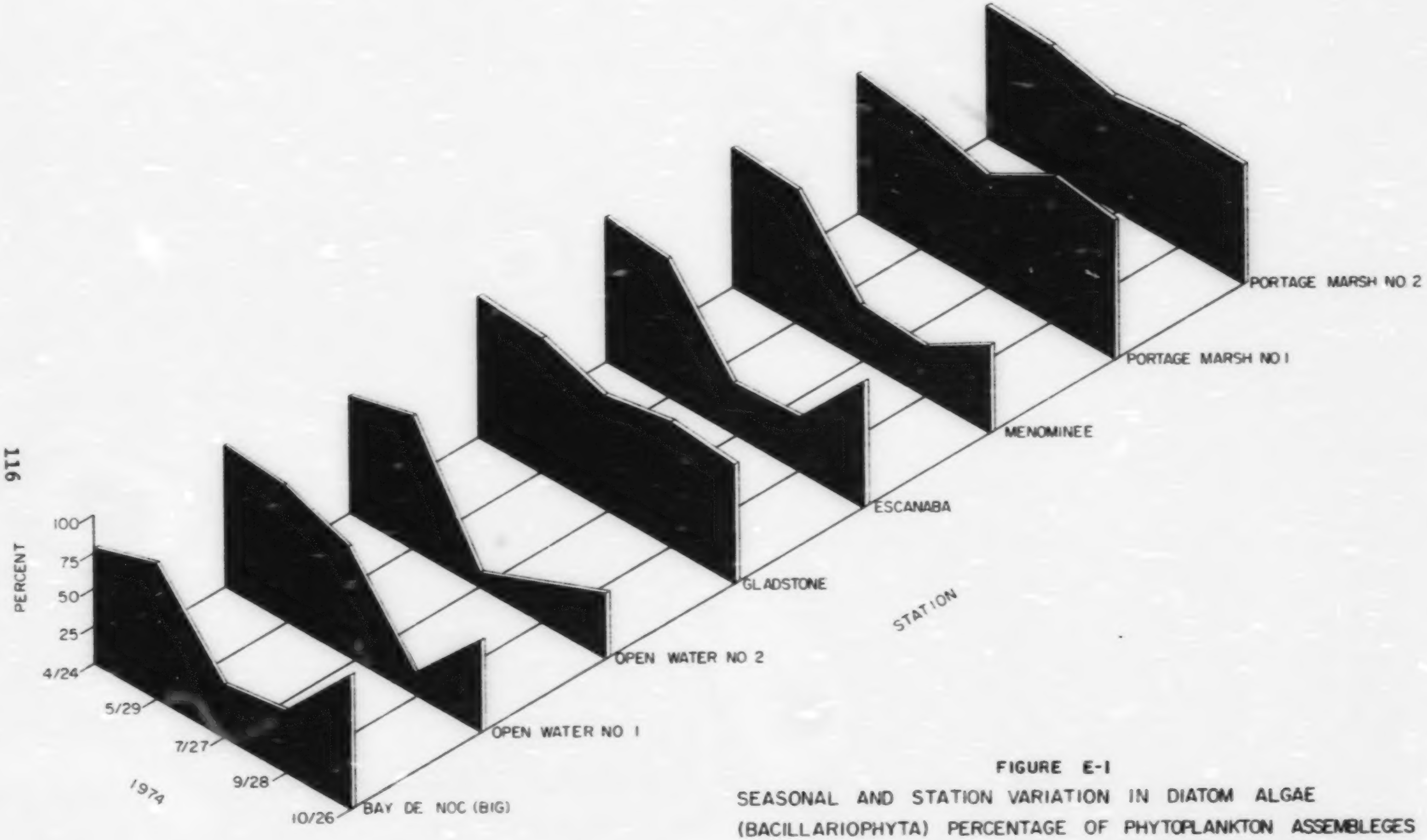

FIGURE E-1

SEASONAL AND STATION VARIATION IN DIATOM ALGAE (BACILLARIOPHYTA) PERCENTAGE OF PHYTOPLANKTON ASSEMBLEGES IN NORTHERN GREEN BAY (LAKE MICHIGAN) IN 1974.

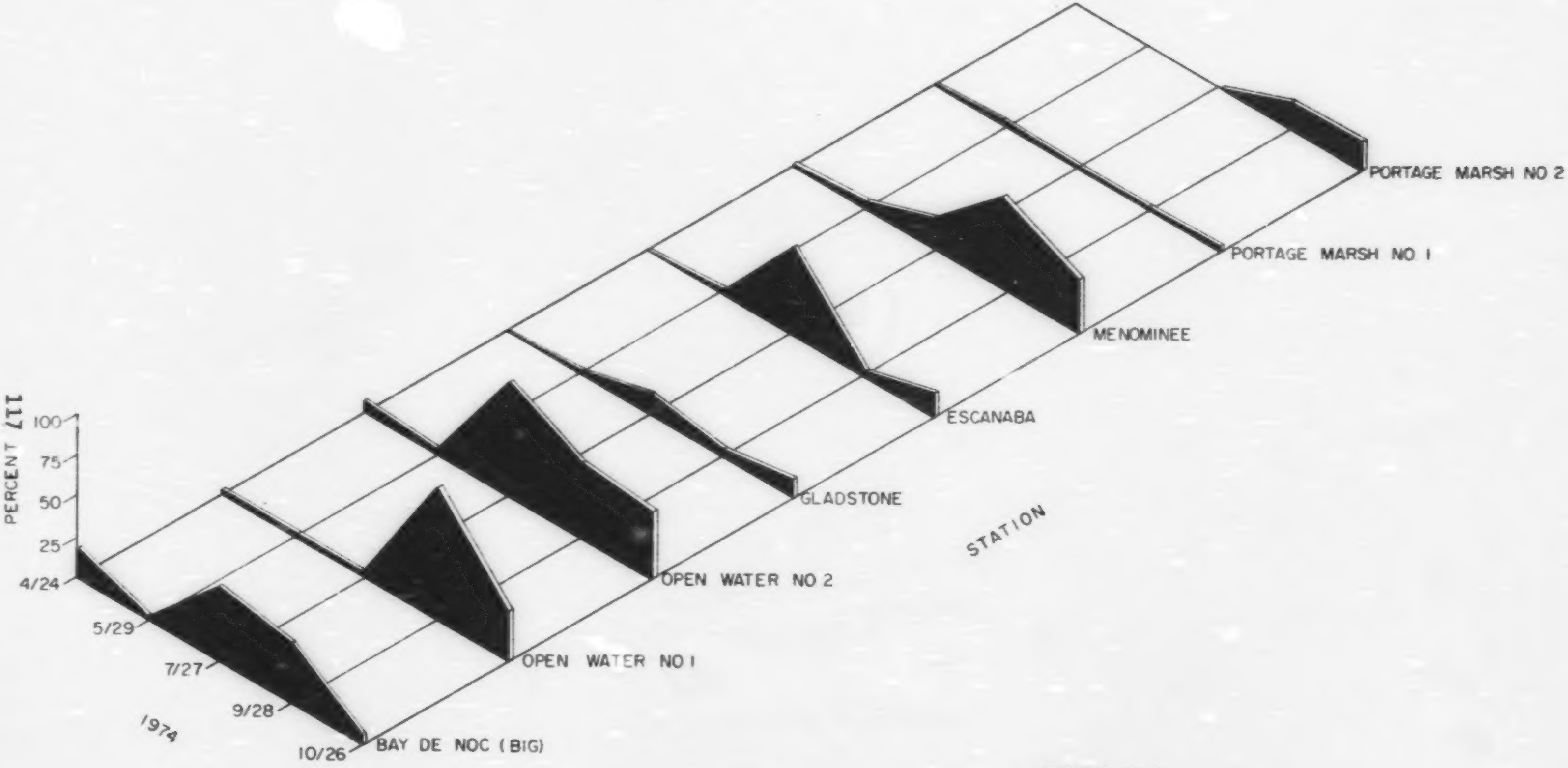

FIGURE E-2

SEASONAL AND STATION VARIATION IN BLUE-GREEN ALGAE (CYANOPHYTA) PERCENTAGE OF PHYTOPLANKTON ASSEMBLAGES IN NORTHERN GREEN BAY (LAKE MICHIGAN) IN 1974.

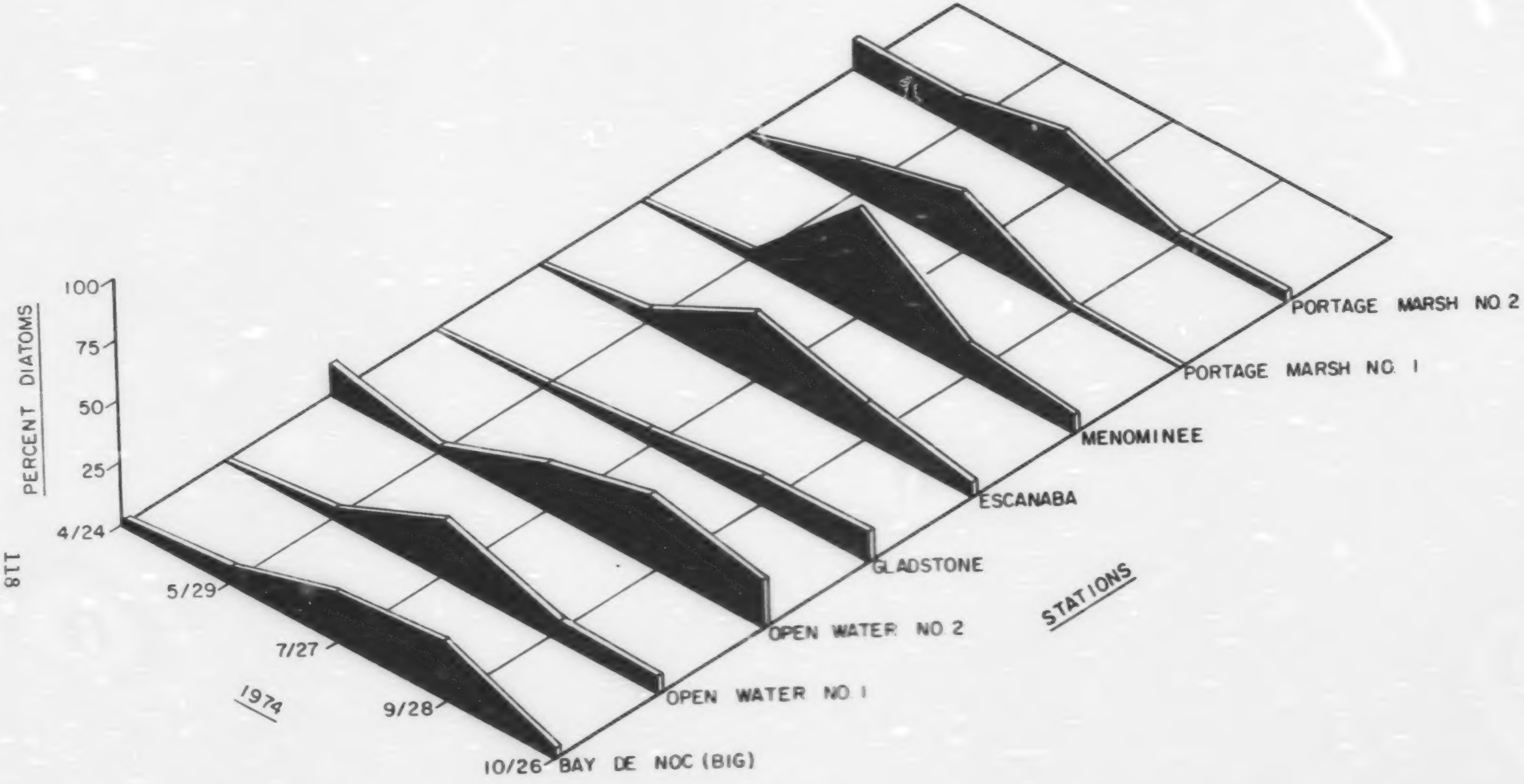

FIGURE E-3

SEASONAL AND STATION VARIATION IN GREEN ALGAE (CHLOROPHYTA) PERCENTAGE OF PHYTOPLANKTON ASSEMBLAGES IN NORTHERN GREEN BAY (LAKE MICHIGAN) IN 1974.

There are definite seasonal and station differences in taxa distribution and dominance.

All stations were diatom-dominated in April and May. They comprise over 90% of the phytoplankton assemblages in May. Little Bay de Noc stations (Gladstone and Escanaba) had the greatest percentage (94-99%). *Fragilaria crontonensis* was the dominant species. It comprised 24% (Menominee - offshore) to 56% (Escanaba) of the population.

During the summer (July) and early fall (September), the species composition shifted. Over-all, for all stations, diatoms comprised 47%, blue-green 36% and green 18% in contrast to spring percentages of 93%, 4% and 2%, respectively. The largest shift occurred at the middle Green Bay stations (Menominee - nearshore and offshore). Blue-green and green species comprised 71% and 18% of the taxa in July (Tables E-5 and E-6) compared to 2% and 0.6%, respectively, in April (Figures E-2 and E-3). Only Gladstone (Little Bay de Noc) remained diatom dominated (>75% of population) throughout the April-October period. Escanaba (Little Bay de Noc), with the exception of a shift to blue-green species (51%) in July, was also diatom dominated (Table E-3). July and September increases in blue-green and green taxa were also noted in upper Green Bay and Big Bay de Noc (Figures E-1, E-2, and E-3).

In middle Green Bay (Menominee - nearshore and offshore) *Oscillatoria retzii* was the most common blue-green algal species in July and September. It comprised 32.5% of the phytoplankton population in the offshore and nearshore stations. Highest occurrence (57%) was at Menominee (nearshore) in September. Historically, its distribution is limited to shallow eutrophic embayments. It has been described in Saginaw Bay (Stoermer, personal communication, 1974). Other species common to middle Green Bay (> 10% of population) included *Mougeotia ap*, *Diatoma tenue var. elongatum* and *Anacystis incerta*, at the offshore station and *Diatoma tenue var. elongatum* nearshore.

The blue-greens, *Gomphosphaaeria aponina* and *Anacystis incerta*, comprised 24% and 14% of the phytoplankton in Big Bay de Noc in July while the green alga, *Glueocystis planctonica* and the diatom *T. fenestrata var. intermedia* represented 11% and 14%, respectively. By September *Anacystis incerta* represented 28% of the population and *Fragilaria crotenensis* was the most common (29%).

Upper Green Bay in July was dominated (>10% population) by the diatoms *F. crotonensis* (45%), *T. fenestrata var. intermedia* (12%) and *Asterionella formosa* (10%). The green alga *Oocystis sp.* comprised 18% of the population. In September the diatom and green algae dominance was replaced by the blue-green *Gompohsphaeria wichurae*

(46%) and *Oscillatoria retzii* (29%). The July blue-green shift in Escanaba (Little Bay de Noc) was due to the dominance of one species, *Anacystis incerta* (50%). By October (Figures E-1, E-2 and E-3) the phytoplankton population had shifted once again to diatoms. Holland (1969) observed a late spring (May) and fall (October) maxima for diatom populations in middle Green Bay similar to that observed here for Big Bay de Noc, middle and upper Green Bay.

The two embayments (Little and Big Bay de Noc) and northern Green Bay have distinct differences in phytoplankton species composition. Over-all, on the basis of diatom percentage throughout the ice-free period (April-October), diatoms comprised 84% of the population in Little Bay de Noc, 67% in Big Bay de Noc, 70% in upper Green Bay and 57% in middle Green Bay (Menominee - nearshore and offshore). There was also noted an open water and nearshore difference in diatom dominance similar to Schelske *et al.*, (1971) findings in Lake Michigan. Diatoms were a more dominant component of the phytoplankton population at the nearshore Menominee station (65%) than the open water station (50%).

The importance of the large species shift from diatoms to blue-green populations has been reported by Schelske *et al.*, (1971) and Schelske and Stoermer (1972). They have concluded the shift in phytoplankton species composition is due to a continued input of phosphorus, which is followed by a decline in silica concentration due to increased diatom growth. As the supply of silica becomes limiting relative to available phosphorus, diatoms are replaced by blue-green and green algae. They also noted that a shift to a predominance of blue-green and green algae did not necessarily occur with an increase in cell number. Total cell number was often similar or lower than diatom dominated population (Schelske and Stoeemer, 1972). Thd data-from northern Green Bay fits their observations. Total cell number was similar at all stations (Appendix C, Figure C-5), but shifts to blue-green and green algal dominance occurred in the summer and was most prominent in middle Green Bay (Menominee - offshore). The degree of species shift is apparently related to the silica concentrations in northern Green Bay and middle Green Bay. Figure C-7 in Appendix C indicated the average silicate concentrations in the surface water for this study. Highest values are found in Little Bay de Noc and Menominee (nearshore and offshore). The former was diatom dominated and silica was not limiting to growth. The Menominee (nearshore) station experienced a blue-green and green algal shift, but less than at the open water station (Table E-5 and E-6). Even though average silica levels were approximately double the concentrations found in Little Bay de Noc, some silica limitation occurred at the Menominee nearshore station. The Big Bay de Noc and upper Green Bay stations had average silicate values approximately one-half of Little Bay de Noc (Figure C-7). A summer increase in blue-green and green algae were also noted. Silica presumably was also limiting here relative to available phosphorus supply in the euphotic zone.

Diatoms, blue-green and green taxa comprised over 99% of the phytoplankton assemblage. Chrysophytes, cryptomonads and dinoflagellates comprised only 1%. For species enumeration of the latter organisms, refer to Appendix F.

Taste and Odor Algal Species

Biological odor of an earthy-musty character in surface water is not only attributed to metabolites of selected actinomycete species. Blue-green algal species are also associated with this particular odor. Members of both groups have produced the characteristic odor under laboratory conditions (Gerber, 1967; Safferman *et al*., 1967; Medsker *et al*., 1968). Two compounds have been separated from cultures and identified as the chemical agent (Gerber, 1967). One, geosmin, has been identified as a metabolite of several species of blue-green algae (Safferman *et al*., 1967; Medsker *et al*., 1968).

In assessing the biologic source of the earthy-musty odor in northern Green Bay, the blue-green fraction of the phytoplankton population was screened. Species found in Appendix H were compared to odor producing species as reported in the literature. Many blue-green algae capable of producing earthy-musty odor compounds are in the *Oscillatoria* genus. Only two species of *Oscillatoria* were rather abundant in northern Green Bay during July; *Oscillatoria retzii* was the dominant component in samples from middle Green Bay and *Oscillatoria limnetica* was occasionally present. Neither of the benthic blue-greens, *Oscillatoria tenus* or *Oscillatoria chalybea*, were noted. Both have been identified as the principle causative agent of earthy-musty odor in reservoirs (Aschner *et al*., 1968; Leventer and Eren, 1970).

Inasmuch as *O. retzii* is a benthic alga and is only facultatively planktonic (Stoermer, personal communication, 1974), its presence in our epilimnion samples is suggestive of the presence of an unsampled benthic algal community. Stoermer (personal communication, 1974) indicates benthic algal community. Stoermer (personal communication, 1974) indicates benthic algal mats are present in northern Green Bay. Through the use of SCUBA techniques, a qualitative survey of the benthos was conducted in June (1974). Zones in Little Bay de Noc, upper Green Bay and middle Green Bay were selected. Little benthic algal growth was observed and no blue-green taxa were identified. Though blue-green taxa are not conclusively eliminated as a source of the earthy-musty odor, their implication, at this point in time, must be considered minimal.

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Appendix F

Cell counts (cells/ml), percent abundance and species enumeration of algal taxa in northern Green Bay (Lake Michigan) in 1974.

Table F-1. Cell counts (cells/ml), percent abundance and species enumeration of algal taxa in northern Green Bay (Lake Michigan) from eight stations on 24-25 April, 1974.

Big Bay de Noc	Species Present	
24-25 April	cells	percent
Fragilaria crotonensis (DI)	534.1	31.002
Gomphosphaeria wichurae (BG)	314.2	18.248
Synedra filiformis (DI)	173.8	10.097
Tabellaria fenestrata var. intermedia (DI)	94.2	5.474
Tabellaria flocculosa (DI)	79.6	4.623
Cyclotella stelligera (DI)	58.6	3.406
Achnanthes minutissima (DI)	52.4	3.041
Rhizosolenia eriensis (DI)	52.4	3.041
Stephanodiscus minutus (DI)	35.6	2.068
Cyclotella michiganiana (DI)	27.2	1.582
Ulothrix sp. #1 (GR)	25.1	1.460
Asterionella formosa (DI)	20.9	1.217
Rhizosolenia gracilis (DI)	20.9	1.217
Synedra tenera (DI)	20.9	1.217
Melosira italica (DI)	18.8	1.095
Dinobryon cysts (CH)	16.8	0.973
Melosira islandica (DI)	14.7	0.852
Amphora ovalis var. pediculus (DI)	8.4	0.487
Diatoma tenue (DI)	8.4	0.487
Rhodomonas minuta var. nannoplanctica (CR)	8.4	0.487
Nitzschia bacata (DI)	8.4	0.487
Stephanodiscus tenuis (DI)	8.4	0.487
Synedra ulna (DI)	8.4	0.487
Navicula questionable sp. #1 (DI)	6.3	0.365
Nitzschia questionable sp. #1 (DI)	6.3	0.365
Stephanodiscus alpinus (DI)	6.3	0.365
Stephanodiscus hantzschii (DI)	6.3	0.365
Stephanodiscus subtilis (DI)	6.3	0.365
Cymbella subventricosa (DI)	4.2	0.243
Cocconeis diminuta (DI)	4.2	0.243
Cyclotella ocellata (DI)	4.2	0.243
Navicula cryptocephala (DI)	4.2	0.243
Navicula pupula (DI)	4.2	0.243
Nitzschia kutzingiana (DI)	4.2	0.243
Oscillatoria retzii (BG)	4.2	0.243
Stephanodiscus niagarae (DI)	4.2	0.243
Synedra capitata (DI)	4.2	0.243
Achnanthes kryophila (DI)	2.1	0.122
Achnanthes minutissima var. cryptocephala (DI)	2.1	0.122
Achnanthes questionable sp. #1 (DI)	2.1	0.122
Amphora ovalis (DI)	2.1	0.122
Amphora veneta var. angularis (DI)	2.1	0.122

Table F-1. (cont'd.)

Big Bay de Noc	Species Present	
24-25 April	cells	percent
Amphipleura pellucida (DI)	2.1	0.122
Cymbella cistula (DI)	2.1	0.122
Cryptomonas sp. #2 (CR)	2.1	0.122
Diatoma vulgaris (DI)	2.1	0.122
Diploneis oculata (DI)	2.1	0.122
Fragilaria pinnata (DI)	2.1	0.122
Navicula explanata (DI)	2.1	0.122
Navicula questionable sp. #2 (DI)	2.1	0.122
Nitzschia acicularis (DI)	2.1	0.122
Nitzschia dissipata (DI)	2.1	0.122
Nitzschia frustulum (DI)	2.1	0.122
Nitzschia luzonensis (DI)	2.1	0.122
Nitzschia sp. #2 (DI)	2.1	0.122
Stephanodiscus transilvanicus (DI)	2.1	0.122
Synedra questionable sp. #1 (DI)	2.1	0.122
Species Total	57	

Upper Green Bay (OW1)		
Fragilaria crotonensis (DI)	552.9	48.708
Tabellaria fenestrata (DI)	131.9	11.624
Rhizosolenia eriensis (DI)	56.5	4.982
Fragilaria capucina (DI)	50.3	4.428
Synedra filiformis (DI)	48.2	4.244
Melosira islandica (DI)	35.6	3.137
Melosira italica (DI)	33.5	2.952
Stephanodiscus minutus (DI)	31.4	2.768
Oscillatoria retzii (BG)	18.8	1.661
Rhizosolenia gracilis (DI)	18.8	1.661
Synedra ostenfeldii (DI)	14.7	1.292
Cyclotella stelligera (DI)	12.6	1.107
Stephanodiscus alpinus (DI)	12.6	1.107
Diatoma tenue var. elongatum (DI)	10.5	0.923
Cyclotella comta (DI)	8.4	0.738
Scenedesmus bicellularis (GR)	8.4	0.738
Stephanodiscus hantzschii (DI)	8.4	0.738
Stephanodiscus niagarae (DI)	8.4	0.738
Stephanodiscus tenuis (DI)	8.4	0.738
Amphora ovalis var. pediculus (DI)	6.3	0.554
Asterionella formosa (DI)	6.3	0.554
Nitzschia acicularis (DI)	6.3	0.554
Nitzschia bacata (DI)	6.3	0.554

Table F-1. (cont'd.)

Upper Green Bay (OW1) 24-25 April	Species Present	
	cells	percent
Amphipleura pellucide (DI)	4.2	0.369
Cymbella prostrata (DI)	4.2	0.369
Cyclotella michiganiana (DI)	4.2	0.369
Navicula pupula (DI)	4.2	0.369
Nitzschia sp. #2 (DI)	4.2	0.369
Amphiprora ornata (DI)	2.1	0.185
Cymbella hybrida (DI)	2.1	0.185
Cymbella microcephala (DI)	2.1	0.185
Closterium aciculare (GR)	2.1	0.185
Cyclotella ocellata (DI)	2.1	0.185
Fragilaria brevistriata var. inflata (DI)	2.1	0.185
Navicula cryptocephala (DI)	2.1	0.185
Nitzschia dissipata (DI)	2.1	0.185
Synedra ulna var. chaseana (DI)	2.1	0.185
Species Total	37	
Middle Green Bay (Menominee-offshore)		
Fragilaria crotonensis (DI)	446.1	24.624
Stephanodiscus subtilis (DI)	324.6	17.919
Ulothrix sp. #1 (GR)	213.6	11.792
Stephanodiscus alpinus (DI)	125.7	6.936
Stephanodiscus minutus (DI)	94.2	5.202
Oscillatoria retzii (BG)	85.9	4.740
Stephanodiscus tenuis (DI)	81.7	4.509
Synedra filiformis (DI)	73.3	4.046
Fragilaria capucina (DI)	62.8	3.468
Asterionella formosa (DI)	54.5	3.006
Rhizosolenia eriensis (DI)	46.1	2.543
Rhizosolenia gracilis (DI)	46.1	2.543
Oscillatoria limnetica (BG)	25.1	1.387
Stephanodiscus hantzschii (DI)	25.1	1.387
Melosira islandica (DI)	12.6	0.694
Rhodomonas minuta var. nannoplanctica (CR)	10.5	0.578
Stephanodiscus niagarae (DI)	10.5	0.578
Synedra delicatissima var. angustissima (DI)	10.5	0.578
Ankistrodesmus sp. #1 (GR)	6.3	0.347
Diatoma tenue var. elongatum (DI)	6.3	0.347
Melosira granulata (DI)	6.3	0.347
Scenedesmus bicellularis (CR)	6.3	0.347
Amphipleura pellucida (DI)	4.2	0.231

Table F-1. (cont'd.)

Middle Green Bay (Menominee-offshore) 24-25 April	Species Present cells	 percent
Anacystis questionable sp. #1 (BG)	4.2	0.231
Nitzschia sp. #2 (DI)	4.2	0.231
Oocystis parva (GR)	4.2	0.231
Achnanthes minutissima (DI)	2.1	0.116
Achnanthes questionable sp. #1 (DI)	2.1	0.116
Amphiprora ornata (DI)	2.1	0.116
Cyclotella ocellata (DI)	2.1	0.116
Cyclotella questionable sp. #1 (DI)	2.1	0.116
Cyclotella stelligera (DI)	2.1	0.116
Dinoflagellate sp. #1 (DN)	2.1	0.116
Dinobryon cysts (CH)	2.1	0.116
Navicula questionable sp. #1 (DI)	2.1	0.116
Stephanodiscus binderanus (DI)	2.1	0.116
Species Total	36	

Gladstone (G)

Achnanthes questionable sp. #1 (DI)	56.5	10.112
Fragilaria crotonensis (DI)	54.5	9.738
Stephanodiscus niagarae (DI)	44.0	7.865
Diatoma tenue var. elongatum (DI)	37.7	6.742
Tabellaria fenestrata (DI)	33.5	5.993
Asterionella formosa (DI)	31.4	5.618
Fragilaria construens var. venter (DI)	18.8	3.371
Amphora ovalis (DI)	16.8	2.996
Amphora ovalis var. pediculus (DI)	12.6	2.247
Stephanodiscus minutus (DI)	12.6	2.247
Diatoma tenure(DI)	10.5	1.873
Fragilaria capucina (DI)	10.5	1.873
Fragilaria pinnata (DI)	10.5	1.873
Navicula pupula (DI)	10.5	1.873
Nitzschia bacata (DI)	10.5	1.873
Nitzschia dissipata (DI)	10.5	1.873
Achnanthes minutissima (DI)	8.4	1.498
Cyclotella comta (DI)	8.4	1.498
Eucocconeis flexella (DI)	8.4	1.498
Stephanodiscus tenuis (DI)	8.4	1.498
Achnanthes clevei (DI)	6.3	1.124
Achnanthes deflexa (DI)	6.3	1.124
Achnanthes lanceolata var. dubia (DI)	6.3	1.124
Fragilaria construens var. pumila (DI)	6.3	1.124

Table F-1. (cont'd.)

Gladstone (G)	Species Present	
24-25 April	cells	percent
Mallomonas alpina (CH)	6.3	1.124
Navicula cryptocephala (DI)	6.3	1.124
Nitzschia filiformis (DI)	6.3	1.124
Nitzschia palea (DI)	6.3	1.124
Achnanthes lanceolata (DI)	4.2	0.749
Achnanthes questionable sp. #2 (DI)	4.2	0.749
Caloneis bacillum (DI)	4.2	0.749
Cymbella cistula var. #1 (DI)	4.2	0.749
Cocconeis placentula (DI)	4.2	0.749
Navicula explanata (DI)	4.2	0.749
Navicula menisculus var. upsaliensis (DI)	4.2	0.749
Navicula radiosa var. tenella (DI)	4.2	0.749
Rhizosolenia gracilis (DI)	4.2	0.749
Achnanthes biasolettiana (DI)	2.1	0.375
Achnanthes clevei var. rostrata (DI)	2.1	0.375
Amphiprora ornata (DI)	2.1	0.375
Caloneis questionable sp. #1 (DI)	2.1	0.375
Cymbella laevis (DI)	2.1	0.375
Cymbella microcephala (DI)	2.1	0.375
Cyclotella michiganiana (DI)	2.1	0.375
Cyclotella stelligera (DI)	2.1	0.375
Denticula tenuis (DI)	2.1	0.375
Fragilaria leptostauron var. dubia (DI)	2.1	0.375
Gomphonema angustatum (DI)	2.1	0.375
Gomphonema intricatum var. pumila (DI)	2.1	0.375
Gomphonema parvulum (DI)	2.1	0.375
Melosira italica (DI)	2.1	0.375
Meridion circulare (DI)	2.1	0.375
Navicula reinhardtii (DI)	2.1	0.375
Navicula subhamulata (DI)	2.1	0.375
Navicula similis (DI)	2.1	0.375
Navicula viridula (DI)	2.1	0.375
Nitzschia acicularis (DI)	2.1	0.375
Nitzschia fonticola (DI)	2.1	0.375
Nitzschia sp. #2 (DI)	2.1	0.375
Oscillatoria retzii (BG)	2.1	0.375
Stephanodiscus hantzschii (DI)	2.1	0.375
Synedra filiformis (DI)	2.1	0.375
Synedra ostenfeldii(DI)	2.1	0.375
Synedra ulna var. aequalis (DI)	2.1	0.375
Species Total	64	

Table F-1. (cont'd.)

Escanaba (E) 24-25 April	Species Present cells	 percent
Fragilaria crotonensis (DI)	800.1	56.845
Tabellaria fenestrata (DI)	104.7	7.440
Melosira italica (DI)	90.1	6.399
Melosira islandica (DI)	73.3	5.208
Diatoma tenue (DI)	33.5	2.381
Stephanodiscus minutus (DI)	29.3	2.083
Nitzschia bacata (DI)	18.8	1.339
Melosira granulata var. angustissima (DI)	16.8	1.190
Achnanthes minutissima (DI)	14.7	1.042
Achnanthes questionable sp. #2 (girdle views) (DI)	12.6	0.893
Amphora ovalis var. pediculus (DI)	12.6	0.893
Synedra filiformis (DI)	12.6	0.893
Achnanthes questionable sp. #1 (girdle views) (DI)	10.5	0.744
Amphora ovalis (DI)	10.5	0.744
Amphipleura pellucida (DI)	10.5	0.744
Synedra ostenfeldii (DI)	10.5	0.744
Diatoma tenue var. elongatum (DI)	8.4	0.595
Synedra ulna var. aequalis (DI)	8.4	0.595
Cyclotella comta (DI)	6.3	0.446
Cyclotella stelligera (DI)	6.3	0.446
Navicula cryptocephala (DI)	6.3	0.446
Navicula vanheurckii (DI)	6.3	0.446
Achnanthes clevei (DI)	4.2	0.298
Anomoeoneis vitrea (DI)	4.2	0.298
Cymbella microcephala (DI)	4.2	0.298
Cocconeis disculus (DI)	4.2	0.298
Cocconeis placentula (DI)	4.2	0.298
Fragilaria construens var. venter (DI)	4.2	0.298
Rhoicosphenia curvata (DI)	4.2	0.298
Stephanodiscus niagarae (DI)	4.2	0.298
Stephanodiscus transilvanicus (DI)	4.2	0.298
Achnanthes clevei var. rostrata (DI)	2.1	0.149
Achnanthes lanceolata (DI)	2.1	0.149
Achnanthes microcephala (DI)	2.1	0.149
Cymbella delicatula (DI)	2.1	0.149
Cymbella hybrida (DI)	2.1	0.149
Cymbella laevis (DI)	2.1	0.149
Cymbella latens (DI)	2.1	0.149
Cymbella prostrata (DI)	2.1	0.149
Cymbella turgida var. pseudogracilis (DI)	2.1	0.149
Cyclotella cryptica (DI)	2.1	0.149
Cyclotella meneghiniana var. plana (DI)	2.1	0.149
Eunotia arcus (DI)	2.1	0.149
Fragilaria pinnata (DI)	2.1	0.149
Fragilaria vaucheriae (DI)	2.1	0.149
Gomphonema olivaceum (DI)	2.1	0.149

Table F-1. (cont'd.)

Escanaba (E)	Species Present	
24-25 April	cells	percent
Gomphonema parvulum (DI)	2.1	0.149
Mallomonas alpina (CH)	2.1	0.149
Meridion circulare (DI)	2.1	0.149
Navicula globosa (DI)	2.1	0.149
Navicula gregaria (DI)	2.1	0.149
Navicula gysingensis (DI)	2.1	0.149
Navicula menisculus var. upsaliensis (DI)	2.1	0.149
Navicula pupula (DI)	2.1	0.149
Navicula radiosa (DI)	2.1	0.149
Navicula radiosa var. tenella (DI)	2.1	0.149
Navicula questionable sp. #1 (DI)	2.1	0.149
Navicula viridula (DI)	2.1	0.149
Nitzschia frustulum (DI)	2.1	0.149
Nitzschia kutzingiana (DI)	2.1	0.149
Stephanodiscus alpinus (DI)	2.1	0.149
Stephanodiscus tenuis (DI)	2.1	0.149
Surirella linearis (DI)	2.1	0.149
Species Total	63	

Menominee - nearshore (M)	cells	percent
Fragilaria crotonensis (DI)	546.6	39.486
Fragilaria capucina (DI)	188.5	13.616
Tabellaria fenestrata (DI)	67.0	4.841
Stephanodiscus minutus (DI)	48.2	3.480
Stephanodiscus tenuis (DI)	48.2	3.480
Fragilaria pinnata (DI)	41.9	3.026
Synedra filiformis (DI)	37.7	2.723
Asterionella formosa (DI)	27.2	1.967
Oscillatoria retzii (BG)	27.2	1.967
Fragilaria construens var. venter (DI)	25.1	1.815
Nitzschia bacata (DI)	25.1	1.815
Diatoma tenue (DI)	23.0	1.664
Nitzschia dissipata (DI)	23.0	1.664
Amphora ovalis var. pediculus (DI)	14.7	1.059
Stephanodiscus alpinus (DI)	14.7	1.059
Stephanodiscus hantzschii (DI)	14.7	1.059
Cyclotella stelligera (DI)	12.6	0.908
Diatoma tenue var. elongatum (DI)	12.6	0.908
Synedra ulna (DI)	12.6	0.908
Achnanthes questionable sp. #1 (girdle views) (DI)	10.5	0.756
Rhizosolenia gracilis (DI)	10.5	0.756

Table F-1. (cont'd.)

Menominee - nearshore (M) 24-25 April	Species Present cells	 percent
Stephanodiscus niagarae (DI)	10.5	0.756
Gomphonema questionable sp. #1 (girdle views) (DI)	8.4	0.605
Rhizosolenia eriensis (DI)	8.4	0.605
Scenedesmus quadricauda (GR)	8.4	0.605
Achnanthes lanceolata (DI)	6.3	0.454
Meridion circulare (DI)	6.3	0.454
Navicula cryptocephala (DI)	6.3	0.454
Navicula menisculus var. upsaliensis (DI)	6.3	0.454
Achnanthes linearis (DI)	4.2	0.303
Cymbella ventricosa (DI)	4.2	0.303
Cyclotella operculata (DI)	4.2	0.303
Gomphonema olivaceum (DI)	4.2	0.303
Navicula pupula (DI)	4.2	0.303
Nitzschia acicularis (DI)	4.2	0.303
Nitzschia fonticola (DI)	4.2	0.303
Nitzschia sp. #2 (DI)	4.2	0.303
Rhoicosphenia curvata (DI)	4.2	0.303
Stephanodiscus subtilis (DI)	4.2	0.303
Achnanthes clevei var. rostrata (DI)	2.1	0.151
Achnanthes exigua var. constricta (DI)	2.1	0.151
Achnanthes kryophila var. africana (DI)	2.1	0.151
Amphora neglecta (DI)	2.1	0.151
Amphora ovalis (DI)	2.1	0.151
Amphipleura pellucida (DI)	2.1	0.151
Cocconeis placentula (DI)	2.1	0.151
Cyclotella comta (DI)	2.1	0.151
Cyclotella kutzingiana (DI)	2.1	0.151
Cyclotella michiganiana (DI)	2.1	0.151
Cyclotella ocellata (DI)	2.1	0.151
Diatoma vulgaris (DI)	2.1	0.151
Rhodomonas minuta var. nannoplanctica (CR)	2.1	0.151
Fragilaria construens (DI)	2.1	0.151
Gomphonema angustatum (DI)	2.1	0.151
Melosira islandica (DI)	2.1	0.151
Navicula radiosa (DI)	2.1	0.151
Navicula similis (DI)	2.1	0.151
Navicula questionable sp. #1 (DI) (unidentifiable girdle view) (DI)	2.1	0.151
Navicula tripunctata (DI)	2.1	0.151
Navicula vanheurckii (DI)	2.1	0.151
Nitzschia palea (DI)	2.1	0.151
Synedra ostenfeldii (DI)	2.1	0.151
Synedra ulna var. chaseana (DI)	2.1	0.151
Species Total	63	

Table F-1. (cont'd.)

Portage Marsh (PM1)	Species Present	
24-25 April	cells	percent
Fragilaria crotonensis (DI)	391.7	39.957
Tabellaria fenestrata (DI)	75.4	7.692
Synedra filiformis (DI)	41.9	4.274
Stephanodiscus minutus (DI)	39.8	4.060
Diatoma tenue var. elongatum (DI)	37.7	3.846
Melosira italica (DI)	37.7	3.846
Stephanodiscus tenuis (DI)	23.0	2.350
Amphora ovalis var. pediculus (DI)	20.9	2.137
Achnanthes questionable sp. #1 (girdle view) (DI)	18.8	1.923
Fragilaria construens var. venter (DI)	18.8	1.923
Stephanodiscus niagarae (DI)	18.8	1.923
Asterionella formosa (DI)	16.8	1.709
Rhizosolenia eriensis (DI)	16.8	1.709
Navicula vanheurckii (DI)	14.7	1.496
Stephanodiscus alpinus (DI)	14.7	1.496
Amphora ovalis (DI)	12.6	1.282
Melosira islandica (DI)	12.6	1.282
Rhizosolenia gracilis (DI)	12.6	1.282
Oscillatoria retzii (BG)	10.5	1.068
Achnanthes lanceolata (DI)	8.4	0.855
Amphipleura pellucida (DI)	8.4	0.855
Nitzschia bacata (DI)	8.4	0.855
Nitzschia dissipata (DI)	8.4	0.855
Achnanthes minutissima (DI)	6.3	0.641
Cyclotella michiganiana (DI)	6.3	0.641
Cyclotella stelligera (DI)	6.3	0.641
Navicula cryptocephala (DI)	6.3	0.641
Achnanthes biasolettiana (DI)	4.2	0.427
Achnanthes clevei var. rostrata (DI)	4.2	0.427
Achnanthes deflexa (DI)	4.2	0.427
Cyclotella comta (DI)	4.2	0.427
Cyclotella ocellata (DI)	4.2	0.427
Dinoflagellate sp. #1 (DN)	4.2	0.427
Diatoma tenue (DI)	4.2	0.427
Navicula paludosa (DI)	4.2	0.427
Nitzschia palea (DI)	4.2	0.427
Rhoicosphenia curvata (DI)	4.2	0.427
Staurastrum paradoxum (GR)	4.2	0.427
Stephanodiscus hantizschii (DI)	4.2	0.427
Cymbella microcephala (DI)	2.1	0.214
Cymbella parvula (DI)	2.1	0.214
Cymbella prostrata (DI)	2.1	0.214
Cymbella sinuata (DI)	2.1	0.214
Cocconeis placentula (DI)	2.1	0.214
Cyclotella meneghiniana (DI)	2.1	0.214
Cyclotella operculata (DI)	2.1	0.214

Table F-1. (cont'd.)

Portage Marsh (PM1)	Species Present	
24-25 April	cells	percent
Denticula tenuis var. crassula (DI)	2.1	0.214
Fragilaria vaucheriae (DI)	2.1	0.214
Navicula gregaria (DI)	2.1	0.214
Navicula odiosa (DI)	2.1	0.214
Navicula pseudoscutiformis (DI)	2.1	0.214
Navicula pupula (DI)	2.1	0.214
Nitzschia acicularis (DI)	2.1	0.214
Nitzschia sp. #2 (DI)	2.1	0.214
Synedra ostenfeldii (DI)	2.1	0.214
Synedra ulna (DI)	2.1	0.214
Species Total	56	

Portage Marsh (PM2)		
Fragilaria crotonensis (DI)	215.7	13.342
Coccomyxa coccoides (GR)	146.6	9.067
Fragilaria construens var. pumila (DI)	131.9	8.161
Fragilaria construens var. venter (DI)	123.6	7.642
Diatoma tenue var. elongatum (DI)	121.5	7.513
Fragilaria construens (DI)	60.7	3.756
Achnanthes lanceolata (DI)	50.3	3.109
Tabellaria fenestrata (DI)	50.3	3.109
Stephanodiscus subtilis (DI)	46.1	2.850
Stephanodiscus tenuis (DI)	39.8	2.461
Cyclotella stelligera (DI)	35.6	2.202
Rhoicosphenia curvata (DI)	35.6	2.202
Fragilaria capucina (DI)	31.4	1.943
Synedra filiformis (DI)	25.1	1.554
Asterionella formosa (DI)	23.0	1.425
Stephanodiscus minutus (DI)	23.0	1.425
Nitzschia bacata (DI)	20.9	1.295
Melosira granulata (DI)	18.8	1.166
Melosira italica (DI)	16.8	1.036
Nitzschia dissipata (DI)	16.8	1.036
Stephanodiscus niagarae (DI)	16.8	1.036
Diatoma tenue (DI)	14.7	0.907
Fragilaria intermedia var. fallax (DI)	14.7	0.907
Melosira islandica (DI)	14.7	0.907
Navicula menisculus (DI)	14.7	0.907
Rhizosolenia eriensis (DI)	14.7	0.907
Cocconeis placentula (DI)	12.6	0.777
Gomphonema olivaceum (DI)	12.6	0.777
Achnanthes hungarica (DI)	10.5	0.648

Table F-1. (cont'd.)

Portage Marsh (PM2)	Species Present	
24-25 April	cells	percent
Amphora ovalis var. pediculus (DI)	10.5	0.648
Cyclotella meneghiniana (DI)	10.5	0.648
Cyclotella ocellata (DI)	10.5	0.648
Fragilaria pinnata var. intercedens (DI)	10.5	0.648
Navicula gregaria (DI)	10.5	0.648
Nitzschia acicularis (DI)	10.5	0.648
Achnanthes linearis fo. curta (DI)	8.4	0.518
Cyclotella comta (DI)	8.4	0.518
Fragilaria construens var. binodis (DI)	8.4	0.518
Fragilaria vaucheriae (DI)	8.4	0.518
Navicula cryptocephala (DI)	8.4	0.518
Navicula exigua var. capitata (DI)	8.4	0.518
Nitzschia palea (DI)	8.4	0.518
Nitzschia sublinearis (DI)	8.4	0.518
Oocystis parva (GR)	8.4	0.518
Stephanodiscus alpinus (DI)	8.4	0.518
Navicula pupula (DI)	6.3	0.389
Navicula vanheurckii (DI)	6.3	0.389
Nitzschia amphibia (DI)	6.3	0.389
Achnanthes lanceolata var. dubia (DI)	4.2	0.259
Achnanthes linearis (DI)	4.2	0.259
Amphora ovalis (DI)	4.2	0.259
Gomphonema angustatum (DI)	4.2	0.259
Mallomonas questionable sp. #1 (file #6) (CH)	4.2	0.259
Navicula menisculus var. upsaliensis (DI)	4.2	0.259
Navicula odiosa (DI)	4.2	0.259
Oscillatoria limnetica (BG)	4.2	0.259
Synedra ulna (DI)	4.2	0.259
Achnanthes minutissima (DI)	2.1	0.130
Achnanthes sp. #1 (DI)	2.1	0.130
Amphipleura pellucida (DI)	2.1	0.130
Cymbella prostrata (DI)	2.1	0.130
Cymbella questionable sp. #1 (file name #20 undecided species) (DI)	2.1	0.130
Cosmarium sp. #1 (GR)	2.1	0.130
Cyclotella michiganiana (DI)	2.1	0.130
Eunotica arcus (DI)	2.1	0.130
Epithemia sorex (DI)	2.1	0.130
Eucocconeis flexella (DI)	2.1	0.130
Fragilaria leptostauron (DI)	2.1	0.130
Gomphonema angustatum var. producta (DI)	2.1	0.130
Gomphonema constrictum (DI)	2.1	0.130
Gomphonema olivaceum var. calcarea (DI)	2.1	0.130
Gomphonema parvulum (DI)	2.1	0.130
Navicula capitata (DI)	2.1	0.130
Navicula cuspidata (DI)	2.1	0.130
Navicula gastrum (DI)	2.1	0.130

Table F-1. (cont'd.)

Portage Marsh (PM2) 24-25 April	Species Present cells	 percent
Navicula radiosa var. tenella (DI)	2.1	0.130
Navicula reinhardtii (DI)	2.1	0.130
Navicula scutelloides (DI)	2.1	0.130
Nitzschia obtusa var. nana (DI)	2.1	0.130
Oscillatoria retzii (BG)	2.1	0.130
Stauroneis sp. #1 (DI)	2.1	0.130
Surirella angusta (DI)	2.1	0.130
Synedra ostenfeldii (DI)	2.1	0.130
Species Total	83	

Table F-2. Cell counts (cells/ml) percent abundance and species enumeration of algal taxa in northern Green Bay (Lake Michigan) from eight stations on 29-30 May, 1974.

Big Bay de Noc	Species Present	
29-30 May	cells	percent
Cyclotella michiganiana (DI)	310.0	23.492
Fragilaria crotonensis (DI)	303.7	23.016
Tabellaria fenestrata var. intermedia (DI)	257.6	19.524
Rhizosolenia gracilis (DI)	73.3	5.556
Ulothrix sp. #1 (GR)	58.6	4.444
Cyclotella stelligera (DI)	52.4	3.968
Synedra filiformis (DI)	48.2	3.651
Melosira granulata (DI)	27.2	2.063
Rhizosolenia eriensis (DI)	23.0	1.746
Tabellaria flocculosa (DI)	23.0	1.746
Synedra delicatissima (DI)	18.8	1.429
Asterionella formosa (DI)	16.8	1.270
Undetermined flagellate sp. #1 (DI)	16.8	1.270
Achnanthes minutissima (DI)	10.5	0.794
Cyclotella comta (DI)	8.4	0.635
Melosira islandica (DI)	8.4	0.635
Nitzschia bacata (DI)	8.4	0.635
Scenedesmus brevispina (GR)	8.4	0.635
Scenedesmus quadricauda var. maximus (GR)	8.4	0.635
Synedra parasitica (DI)	8.4	0.635
Cyclotella ocellata (DI)	4.2	0.317
Nitzschia acicularis (DI)	4.2	0.317
Achnanthes clevei var. rostrata (DI)	2.1	0.159
Amphiprora ornata (DI)	2.1	0.159
Caloneis bacillum (DI)	2.1	0.159
Cosmarium sp. #1 (GR)	2.1	0.159
Microcoleus vaginatus (BG)	2.1	0.159
Nitzschia dissipata (DI)	2.1	0.159
Nitzschia sp. #1 (DI)	2.1	0.159
Oocystis parva (GR)	2.1	0.159
Stephanodiscus alpinus (DI)	2.1	0.159
Stephanodiscus niagarae (DI)	2.1	0.159
Species Total	32	

Table F-2. (cont'd.)

Upper Green Bay (OW1)	Species Present	
29-30 May	cells	percent
Fragilaria crotonensis (DI)	515.2	29.426
Synedra filiformis (DI)	280.6	16.029
Tabellaria fenestrata var. intermedia (DI)	280.6	16.029
Rhizosolenia gracilis (DI)	180.1	10.287
Cyclotella stelligera (DI)	56.5	3.230
Diatoma tenue var. elongatum (DI)	48.2	2.751
Cyclotella comta (DI)	41.9	2.392
Undetermined flagellate sp. #1 (UN)	37.7	2.153
Ulothrix sp. #1 (GR)	35.6	2.033
Rhizosolenia eriensis (DI)	33.5	1.914
Cyclotella michiganiana (DI)	31.4	1.794
Melosira islandica (DI)	23.0	1.316
Nitzschia acicularis (DI)	23.0	1.316
Cyclotella ocellata (DI)	18.8	1.077
Scenedesmus quadricauda var. longispina (GR)	16.8	0.957
Oscillatoria retzii (BG)	14.7	0.837
Tabellaria flocculosa (DI)	12.6	0.718
Amphipleura pellucida (DI)	10.5	0.598
Dinobryon cysts (CH)	10.5	0.598
Achnanthes minutissima (DI)	8.4	0.478
Asterionella formosa (DI)	8.4	0.478
Synedra delicatissima var. angustissima (DI)	8.4	0.478
Melosira granulata (DI)	6.3	0.359
Synedra ulna (DI)	6.3	0.359
Ankistrodesmus questionable sp. #1 (GR)	4.2	0.239
Cyclotella kutzingiana (DI)	4.2	0.239
Diatoma tenue (DI)	4.2	0.239
Franceia droescheri (GR)	4.2	0.239
Fragilaria construens var. minuta (DI)	4.2	0.239
Synedra questionable sp. #1 (DI)	4.2	0.239
Achnanthes hungarica (DI)	2.1	0.120
Dinobryon sociale (CH)	2.1	0.120
Nitzschia bacata (DI)	2.1	0.120
Nitzschia confinis (DI)	2.1	0.120
Nitzschia kutzingiana (DI)	2.1	0.120
Nitzschia sp. #2 (DI)	2.1	0.120
Nitzschia questionable sp. #1 (DI)	2.1	0.120
Tabellaria fenestrata (DI)	2.1	0.120
Species Total	38	

Table F-2. (cont'd.)

Middle Green Bay (Menominee-offshore) 29-30 May	Species Present cells	 percent
Fragilaria crotonensis (DI)	473.3	26.249
Tabellaria fenestrata var. intermedia (DI)	318.3	17.654
Synedra filiformis (DI)	217.8	12.079
Diatoma tenue var. elongatum (DI)	155.0	8.595
Asterionella formosa (DI)	150.8	8.362
Oscillatoria retzii (BG)	73.3	4.065
Rhizosolenia gracilis (DI)	41.9	2.323
Stephanodiscus tenuis (DI)	33.5	1.858
Cyclotella comta (DI)	29.3	1.626
Stephanodiscus subtilis (DI)	29.3	1.626
Stephanodiscus alpinus (DI)	27.2	1.510
Cyclotella stelligera (DI)	25.1	1.394
Rhizosolenia eriensis (DI)	25.1	1.394
Nitzschia holsatica (DI)	23.0	1.278
Stephanodiscus minutus (DI)	16.8	0.929
Melosira italica (DI)	14.7	0.813
Ulothrix subconstricta (GR)	14.7	0.813
Diatoma tenue (DI)	12.6	0.697
Stephanodiscus niagarae (DI)	12.6	0.697
Ulothrix sp. #1 (GR)	12.6	0.697
Melosira granulata (DI)	10.5	0.581
Nitzschia acicularis (DI)	10.5	0.581
Oscillatoria limnetica (BG)	10.5	0.581
Synedra ulna var. chaseana (DI)	10.5	0.581
Amphipleura pellucida (DI)	6.3	0.348
Fragilaria construens var. pumila (DI)	6.3	0.348
Navicula viridula (DI)	6.3	0.348
Ankistrodesmus brauni (GR)	4.2	0.232
Cosmarium sp. #1 (GR)	4.2	0.232
Cyclotella michiganiana (DI)	4.2	0.232
Mallomonas #6 (CH)	4.2	0.232
Stephanodiscus hantzschii (DI)	4.2	0.232
Synedra ostenfeldii (DI)	4.2	0.232
Achnanthes clevei (DI)	2.1	0.116
Achnanthes sp. #1 (DI)	2.1	0.116
Dinoflagellate sp. #1 (DN)	2.1	0.116
Nitzschia sp. #2 (DI)	2.1	0.116
Peridinium sp. #1 (DN)	2.1	0.116
Species Total	38	

Table F-2. (cont'd.)

Gladstone (G) 29-30 May	Species Present cells	 percent
Fragilaria crotonensis (DI)	446.1	27.168
Diatoma tenue var. elongatum (DI)	171.7	10.459
Fragilaria capucina (DI)	163.4	9.949
Tabellaria fenestrata var. intermedia (DI)	148.7	9.056
Asterionella formosa (DI)	131.9	8.036
Synedra filiformis (DI)	98.4	5.995
Rhizosolenia gracilis (DI)	67.0	4.082
Rhizosolenia eriensis (DI)	58.6	3.571
Tabellaria fenestrata (DI)	48.2	2.934
Cyclotella comta (DI)	35.6	2.168
Stephanodiscus niagarae (DI)	31.4	1.913
Melosira granulata (DI)	27.2	1.658
Anacystis thermalis (BG)	20.9	1.276
Cyclotella michiganiana (DI)	18.8	1.148
Oscillatoria retzii (BG)	18.8	1.148
Cyclotella stelligera (DI)	14.7	0.893
Rhodomonas minuta var. nannoplanctica (CR)	12.6	0.765
Melosira granulata var. angustissima (DI)	12.6	0.765
Synedra ulna var. chaseana (DI)	12.6	0.765
Melosira distans var. alpigena (DI)	10.5	0.638
Stephanodiscus alpinus (DI)	10.5	0.638
Gloeocystis planctonica (BG)	8.4	0.510
Cyclotella kutzingiana (DI)	6.3	0.333
Cyclotella ocellata (DI)	6.3	0.383
Fragilaria construens var. venter (DI)	6.3	0.383
Stephanodiscus hantzschii (DI)	6.3	0.383
Amphipleura pellucida (DI)	4.2	0.255
Cymbella turgida var. pseudogracilis (DI)	4.2	0.255
Mallomonas #6 (CH)	4.2	0.255
Nitzschia acicularis (DI)	4.2	0.255
Nitzschia amphibia (DI)	4.2	0.255
Nitzschia dissipata (DI)	4.2	0.255
Stephanodiscus tenuis (DI)	4.2	0.255
Achnanthes clevei var. rostrata (DI)	2.1	0.128
Achnanthes minutissima (DI)	2.1	0.128
Cymbella hybrida (DI)	2.1	0.128
Cymbella prostrata (DI)	2.1	0.128
Cocconeis placentula (DI)	2.1	0.128
Fragilaria vaucheriae (DI)	2.1	0.128
Nitzschia bacata (DI)	2.1	0.128
Peridinium sp. #1 (DN)	2.1	0.128
Synedra ostenfeldii (DI)	2.1	0.128
Species Total	42	

Table F-2. (cont'd.)

Escanaba (E)	Species Present	
29-30 May	cells	percent
Fragilaria crotonensis (DI)	607.4	39.456
Tabellaria fenestrata var. intermedia (DI)	165.5	10.748
Synedra filiformis (DI)	108.9	7.075
Rhizosolenia gracilis (DI)	100.5	6.531
Diatoma tenue var. elongatum (DI)	96.3	6.258
Asterionella formosa (DI)	85.9	5.578
Tabellaria fenestrata (DI)	39.8	2.585
Stephanodiscus subtilis (DI)	35.6	2.313
Ulothrix sp. #1 (GR)	31.4	2.041
Melosira granulata (DI)	29.3	1.905
Cyclotella stelligera (DI)	25.1	1.633
Oscillatoria retzii (BG)	25.1	1.633
Rhizosolenia eriensis (DI)	25.1	1.633
Cyclotella comta (DI)	23.0	1.497
Oocystis parva (GR)	23.0	1.497
Cyclotella michiganiana (DI)	16.8	1.088
Nitzschia bacata (DI)	12.6	0.816
Synedra ostenfeldii (DI)	12.6	0.816
Nitzschia acicularis (DI)	10.5	0.680
Achnanthes minutissima (DI)	8.4	0.544
Ankistrodesmus questionable sp. #1 (GR)	8.4	0.544
Cyclotella cryptica (DI)	8.4	0.544
Stephanodiscus alpinus (DI)	8.4	0.544
Stephanodiscus niagarae (DI)	8.4	0.544
Stephanodiscus tenuis (DI)	6.3	0.408
Amphipleura pellucida (DI)	4.2	0.272
Achnanthes hungarica (DI)	2.1	0.136
Cyclotella kutzingiana (DI)	2.1	0.136
Microcoleus vaginatus (BG)	2.1	0.136
Nitzschia confinis (DI)	2.1	0.136
Stephanodiscus hantzschii (DI)	2.1	0.136
Synedra ulna var. chaseana (DI)	2.1	0.136
Species Total	32	
Menominee - nearshore (M)		
Tabellaria fenestrata var. intermedia (DI)	548.7	26.070
Fragilaria crotonensis (DI)	506.8	24.080
Synedra filiformis (DI)	169.6	8.060
Asterionella formosa (DI)	111.0	5.274
Rhizosolenia gracilis (DI)	106.8	5.075
Diatoma tenue var. elongatum (DI)	81.7	3.881
Oscillatoria retzii (BG)	73.3	3.483

Table F-2. (cont'd.)

Menominee - nearshore (M) 29-30 May	Species Present cells	 percent
Tabellaria fenestrata (DI)	46.1	2.189
Cyclotella comta (DI)	41.9	1.990
Melosira italica (DI)	41.9	1.990
Rhizosolenia eriensis (DI)	41.9	1.990
Stephanodiscus tenuis (DI)	39.8	1.891
Stephanodiscus minutus (DI)	35.6	1.692
Melosira granulata (DI)	29.3	1.393
Nitzschia acicularis (DI)	27.2	1.294
Stephanodiscus binderanus (DI)	27.2	1.294
Stephanodiscus alpinus (DI)	20.9	0.995
Ulothrix sp. #1 (GR)	20.9	0.995
Stephanodiscus subtilis (DI)	18.8	0.896
Nitzschia bacata (DI)	14.7	0.697
Cyclotella stelligera (DI)	12.6	0.597
Oscillatoria limnetica (BG)	12.6	0.597
Stephanodiscus hantzschii (DI)	12.6	0.597
Stephanodiscus niagarae (DI)	12.6	0.597
Oocystis parva (GR)	8.4	0.398
Amphipleura pellucida (DI)	6.3	0.299
Mallomonas #6 (CH)	6.3	0.299
Synedra ostenfeldii (DI)	6.3	0.299
Achnanthes clevei var. rostrata (DI)	2.1	0.100
Amphiprora ornata (DI)	2.1	0.100
Cymbella prostrata (DI)	2.1	0.100
Cosmarium sp. #1 (GR)	2.1	0.100
Cocconeis placentula (DI)	2.1	0.100
Cyclotella michiganiana (DI)	2.1	0.100
Rhodomonas minuta var. nannoplanctica (CR)	2.1	0.100
Melosira islandica (DI)	2.1	0.100
Mallomonas sp. #3 (CH)	2.1	0.100
Nitzschia recta (DI)	2.1	0.100
Nitzschia sublinearis (DI)	2.1	0.100
Species Total	39	

Portage Marsh (PM1)		
Stephanodiscus subtilis (DI)	366.5	16.026
Fragilaria construens var. venter (DI)	224.1	9.799
Cyclotella stelligera (DI)	152.9	6.685
Gloeocystis planctonica (BG)	129.9	5.678
Fragilaria construens (DI)	123.6	5.403
Fragilaria construens var. pumila (DI)	117.3	5.128
Fragilaria pinnata var. intercedens (DI)	106.8	4.670

Table F-2. (cont'd.)

Portage Marsh (PM1)	Species Present	
29-30 May	cells	percent
Achnanthes lanceolata (DI)	73.3	3.205
Fragilaria construens var. binodis (DI)	73.3	3.205
Stephanodiscus tenuis (DI)	71.2	3.114
Anacystis incerta (BG)	67.0	2.930
Fragilaria crotonensis (DI)	58.6	2.564
Melosira varians (DI)	58.6	2.564
Nitzschia dissipata (DI)	56.5	2.473
Nitzschia amphibia (DI)	46.1	2.015
Melosira granulata (DI)	37.7	1.648
Achnanthes hungarica (DI)	35.6	1.557
Amphora ovalis var. pediculus (DI)	35.6	1.557
Fragilaria capucina (DI)	35.6	1.557
Cyclotella cryptica (DI)	23.0	1.007
Melosira italica (DI)	23.0	1.007
Cyclotella meneghiniana (DI)	20.9	0.916
Nitzschia bacata (DI)	20.9	0.916
Tabellaria fenestrata (DI)	20.9	0.916
Asterionella formosa (DI)	18.8	0.824
Rhoicosphenia curvata (DI)	18.8	0.824
Cocconeis placentula (DI)	16.8	0.733
Fragilaria vaucheriae(DI)	16.8	0.733
Navicula menisculus var. upsaliensis (DI)	16.8	0.733
Amphora ovalis (DI)	14.7	0.641
Achnanthes linearis (DI)	12.6	0.549
Gomphonema parvulum (DI)	10.5	0.458
Mallomonas #6 (CH)	10.5	0.458
Navicula capitata (DI)	10.5	0.458
Navicula gregaria (DI)	10.5	0.458
Nitzschia recta (DI)	10.5	0.458
Achnanthes questionable sp. #1 (DI)	8.4	0.366
Navicula cryptocephala (DI)	8.4	0.366
Nitzschia palea (DI)	8.4	0.366
Nitzschia sublinearis (DI)	8.4	0.366
Stephanodiscus minutus (DI)	8.4	0.366
Synedra filiformis (DI)	8.4	0.366
Cymbella prostrata (DI)	6.3	0.275
Cyclotella michiganiana (DI)	6.3	0.275
Stauroneis sp. #1 (GR)	6.3	0.275
Achnanthes minutissima (DI)	4.2	0.183
Diatoma tenue (DI)	4.2	0.183
Eunotia curvata (DI)	4.2	0.183
Gomphonema angustatum (DI)	4.2	0.183
Meridion circulare (DI)	4.2	0.183
Navicula exigua var. capitata (DI)	4.2	0.183
Navicula pupula (DI)	4.2	0.183
Nitzschia sp. #2 (DI)	4.2	0.183
Peridinium sp. #1 (DN)	4.2	0.183

Table F-2. (cont'd.)

Portage Marsh (PM1)	Species Present	
29-30 May	cells	percent
Amphipleura pellucida (DI)	2.1	0.092
Amphiprora ornata (DI)	2.1	0.092
Cyclotella comta (DI)	2.1	0.092
Eunotia questionable sp. #1 (DI)	2.1	0.092
Gomphonema constrictum (DI)	2.1	0.092
Gomphonema questionable sp. #1 (DI)	2.1	0.092
Navicula clementis var. quadristigmata (DI)	2.1	0.092
Navicula exigua (DI)	2.1	0.092
Navicula pupula var. capitata (DI)	2.1	0.092
Nitzschia fonticola (DI)	2.1	0.092
Nitzschia frustulum (DI)	2.1	0.092
Pinnularia questionable sp. #1 (DI)	2.1	0.092
Stauroneis anceps fo. linearis (GR)	2.1	0.092
Stephanodiscus hantzschii (DI)	2.1	0.092
Synedra ostenfeldii (DI)	2.1	0.092
Synedra rumpens (DI)	2.1	0.092
Species Total	70	

Portage Marsh (PM2)

Fragilaria crotonensis (DI)	395.8	24.901
Tabellaria fenestrata (DI)	301.6	18.972
Synedra filiformis (DI)	161.3	10.145
Gloeocystis planctonica (BG)	150.8	9.486
Diatoma tenue var. elongatum (DI)	83.8	5.270
Rhizosolenia gracilis (DI)	67.0	4.216
Cyclotella michiganiana (DI)	60.7	3.821
Cyclotella comta (DI)	41.9	2.635
Cyclotella stelligera (DI)	35.6	2.240
Fragilaria construens (DI)	27.2	1.713
Synedra ulna var. chaseana (DI)	25.1	1.581
Asterionella formosa (DI)	20.9	1.318
Amphora ovalis var. pediculus (DI)	18.8	1.186
Rhizosolenia eriensis (DI)	14.7	0.922
Stephanodiscus subtilis (DI)	14.7	0.922
Amphipleura pellucida (DI)	10.5	0.659
Melosira granulata (DI)	10.5	0.659
Mougeotia sp. #1 (GR)	10.5	0.659
Ankistrodesmus sp. #1 (GR)	8.4	0.527
Fragilaria construens var. venter (DI)	8.4	0.527
Scenedesmus quadricauda var. longispina (GR)	8.4	0.527
Stephanodiscus alpinus (DI)	8.4	0.527
Stephanodiscus tenuis (DI)	8.4	0.527

Table F-2. (cont'd.)

Portage Marsh (PM2) 29-30 May	Species Present cells	 percent
Cyclotella ocellata (DI)	6.3	0.395
Nitzschia acicularis (DI)	6.3	0.395
Nitzschia flexa (DI)	6.3	0.395
Oscillatoria retzii (BG)	6.3	0.395
Stephanodiscus niagarae (DI)	6.3	0.395
Achnanthes questionable sp. #1 (DI)	4.2	0.264
Amphiprora ornata (DI)	4.2	0.264
Fragilaria vaucheriae (DI)	4.2	0.264
Navicula pupula (DI)	4.2	0.264
Nitzschia bacata (DI)	4.2	0.264
Nitzschia confinis (DI)	4.2	0.264
Stephanodiscus minutus (DI)	4.2	0.264
Achnanthes clevei (DI)	2.1	0.132
Cymbella cistula (DI)	2.1	0.132
Cosmarium sp. #1 (GR)	2.1	0.132
Cyclotella meneghiniana (DI)	2.1	0.132
Dinoflagellate sp. #1 (DN)	2.1	0.132
Fragilaria leptostauron (DI)	2.1	0.132
Fragilaria pinnata var. lancettula (DI)	2.1	0.132
Mallomonas #6 (CH)	2.1	0.132
Navicula aurora (DI)	2.1	0.132
Navicula cryptocephala (DI)	2.1	0.132
Navicula reinhardtii (DI)	2.1	0.132
Navicula vanheurckii (DI)	2.1	0.132
Nitzschia recta (DI)	2.1	0.132
Nitzschia sublinearis (DI)	2.1	0.132
Oscillatoria limnetica (BG)	2.1	0.132
Stephanodiscus hantzschii (DI)	2.1	0.132
Synedra ulna var. constricta (DI)	2.1	0.132
Species Total	52	

Table F-3. Cell counts (cells/ml), percent abundance and species enumeration of algal taxa in northern Green Bay (Lake Michigan) from eight stations on 28-30 July, 1974.

Big Bay de Noc	Species Present	
28-30 July	cells	percent
Gomphosphaeria aponina (BG)	52.4	23.585
Tabellaria fenestrata var. intermedia (DI)	35.6	16.038
Anacystis incerta (BG)	31.4	14.151
Gloeocystis planctonica (BG)	25.1	11.321
Oocystis parva (GR)	16.8	7.547
Cyclotella michiganiana (DI)	12.6	5.660
Anacystis thermalis (BG)	9.4	4.245
Fragilaria crotonensis (DI)	8.4	3.774
Stephanodiscus niagarae (DI)	8.4	3.774
Asterionella formosa (DI)	7.3	3.302
Oscillatoria bornetii (BG)	7.3	3.302
Nitzschia holsatica (DI)	2.1	0.943
Cocconeis placentula (DI)	1.0	0.472
Cyclotella comta (DI)	1.0	0.472
Nitzschia dissipata (DI)	1.0	0.472
Staurastrum paradoxum (GR)	1.0	0.472
Stephanodiscus alpinus (DI)	1.0	0.472
Species Total	17	
Upper Green Bay (OW1)		
Fragilaria crotonensis (DI)	75.4	45.860
Oocystis questionable spp (GR)	29.3	17.834
Tabellaria fenestrata var. intermedia (DI)	19.9	12.102
Asterionella formosa (DI)	16.8	10.191
Cyclotella michiganiana (DI)	8.4	5.096
Scenedesmus incrassatulus (GR)	4.2	2.548
Cosmarium sp. #1 (GR)	2.1	1.274
Cyclotella comta (DI)	2.1	1.274
Achnanthes clevei var. rostrata (DI)	1.0	0.637
Nitzschia dissipata (DI)	1.0	0.637
Nitzschia palea (DI)	1.0	0.637
Rhizosolenia gracilis (DI)	1.0	0.637
Rhoicosphenia curvata (DI)	1.0	0.637
Tetraedron minimum (GR)	1.0	0.637
Species Total	14	

Table F-3. (cont'd.)

Middle Green Bay (Menominee-offshore) 28-30 July	Species Present cells	 percent
Oscillatoria retzii (BG)	150.8	34.532
Gomphosphaeria lacustris (BG)	94.2	21.583
Anacystis incerta (BG)	52.4	11.990
Gloeocystis planctonica (BG)	37.7	8.633
Ulothrix subconstricta (GR)	31.4	7.194
Stephanodiscus niagarae(DI)	16.8	3.837
Aphanizomenon flos-aquae (BG)	12.6	2.878
Fragilaria crotonensis (DI)	8.4	1.918
Scenedesmus quadricauda var. longispina (GR)	8.4	1.918
Stephanodiscus minutus (DI)	8.4	1.918
Tabellaria fenestrata (DI)	5.2	1.199
Rhizosolenia gracilis (DI)	4.2	0.959
Staurastrum paradoxum (GR)	2.1	0.480
Amphipleura pellucida (DI)	1.0	0.240
Lagerheimia ciliata (GR)	1.0	0.240
Mallomonas alpina (CH)	1.0	0.240
Tetraedron minimum (GR)	1.0	0.240
Species Total	17	
Gladstone (G)		
Fragilaria crotonensis (DI)	129.9	44.765
Fragilaria capucina (DI)	48.2	16.606
Anabaena flos-aquae (BG)	35.6	12.274
Asterionella formosa (DI)	22.0	7.581
Rhodomonas minuta var. nannoplanctica (CR)	10.5	3.610
Tabellaria fenestrata var. intermedia (DI)	9.4	3.249
Gloeocystis planctonica (BG)	8.4	2.888
Ulothrix subconstricta (GR)	8.4	2.888
Stephanodiscus niagarae (DI)	6.3	2.166
Cyclotella ocellata (DI)	2.1	0.722
Fragilaria vaucheriae (DI)	2.1	0.722
Achnanthes minutissima (DI)	1.0	0.361
Amphora ovalis (DI)	1.0	0.361
Cyclotella stelligera (DI)	1.0	0.361
Fragilaria brevistriata var. capitata (DI)	1.0	0.361
Navicula reinhardtii (DI)	1.0	0.361
Rhizosolenia gracilis (DI)	1.0	0.361
Stephanodiscus minutus (DI)	1.0	0.361
Species Total	18	

Table F-3. (cont'd.)

Escanaba (E) 28-30 July	Species Present cells	 percent
Anacystis incerta (BG)	157.1	49.834
Fragilaria capucina (DI)	52.4	16.611
Asterionella formosa (DI)	12.6	3.987
Nephrocytium limneticum (GR)	12.6	3.987
Oocystis parva (GR)	12.6	3.987
Tabellaria fenestrata var. intermedia (DI)	12.6	3.987
Fragilaria crotonensis (DI)	9.4	2.990
Scenedesmus quadricauda var. longispina (GR)	8.4	2.658
Cyclotella michiganiana (DI)	5.2	1.661
Ulothrix subconstricta (GR)	5.2	1.661
Anabaena flos-aquae (BG)	4.2	1.329
Stephanodiscus minutus (DI)	4.2	1.329
Stephanodiscus niagarae (DI)	3.1	0.997
Stephanodiscus tenuis (DI)	3.1	0.997
Mallomonas alpina (CH)	2.1	0.664
Stephanodiscus subtilis (DI)	2.1	0.664
Achnanthes lanceolata var. dubia (DI)	1.0	0.332
Achnanthes minutissima (DI)	1.0	0.332
Amphora ovalis var. pediculus (DI)	1.0	0.332
Cryptomonas sp. #1 (CR)	1.0	0.332
Cocconeis placentula (DI)	1.0	0.332
Lagerheimia ciliata (GR)	1.0	0.332
Navicula questionable sp. #1 (DI)	1.0	0.332
Tetraedron minimum (GR)	1.0	0.332
Species Total	24	

Menominee - nearshore (M)

Oscillatoria retzii (BG)	34.6	19.760
Coelastrum microporum (BG)	33.5	19.162
Tabellaria fenestrata var. intermedia (DI)	24.1	13.772
Ulothrix sp. #1 (GR)	18.8	10.778
Ulothrix subconstricta (GR)	14.7	8.383
Stephanodiscus niagarae (DI)	9.4	5.389
Scenedesmus quadricauda var. longispina (GR)	8.4	4.790
Melosira granulata (DI)	7.3	4.192
Stephanodiscus minutus (DI)	6.3	3.593
Stephanodiscus alpinus (DI)	3.1	1.796
Synedra filiformis (DI)	3.1	1.796
Ankistrodesmus gelifactum (GR)	2.1	1.198
Undetermined flagellate sp. #1	2.1	1.198
Amphora ovalis var. pediculus (DI)	1.0	0.599

Table F-3. (cont'd.)

Menominee - nearshore (M)	Species Present	
28-30 July	cells	percent
Asterionella formosa (DI)	1.0	0.599
Cyclotella kutzingiana (DI)	1.0	0.599
Cyclotella stelligera (DI)	1.0	0.599
Nitzschia confinis (DI)	1.0	0.599
Peridinium cinctum (DN)	1.0	0.599
Rhizosolenia gracilis (DI)	1.0	0.599
Species Total	20	

Portage Marsh (PM1)	Species Present	
28-30 July	cells	percent
Melosira granulata (DI)	123.6	29.064
Fragilaria construens var. venter (DI)	33.5	7.882
Gloeocystis planctonica (BG)	29.3	6.897
Melosira islandica (DI)	26.2	6.158
Pediastrum duplex var. clathratum (GR)	16.8	3.941
Pediastrum tetras (GR)	16.8	3.941
Tabellaria fenestrata var. intermedia (DI)	13.6	3.202
Scenedesmus quadricauda var. longispina (GR)	12.6	2.956
Fragilaria construens (DI)	11.5	2.709
Fragilaria crotonensis (DI)	11.5	2.709
Ulothrix subconstricta (GR)	11.5	2.709
Stephanodiscus minutus (DI)	10.5	2.463
Fragilaria pinnata (DI)	9.4	2.217
Oocystis borgei (GR)	7.3	1.724
Stephanodiscus tenuis (DI)	7.3	1.724
Asterionella formosa (DI)	6.3	1.478
Achnanthes lanceolata (DI)	5.2	1.232
Cyclotella meneghiniana (DI)	5.2	1.232
Rhoicosphenia curvata (DI)	5.2	1.232
Achnanthes clevei var. rostrata (DI)	4.2	0.985
Fragilaria capucina (DI)	4.2	0.985
Fragilaria vaucheriae (DI)	4.2	0.985
Cyclotella michiganiana (DI)	3.1	0.739
Nitzschia amphibia (DI)	3.1	0.739
Nitzschia frustulum (DI)	3.1	0.739
Achnanthes questionable sp. #1 (DI)	2.1	0.493
Ankistrodesmus brauni (GR)	2.1	0.493
Undetermined flagellate sp. #1	2.1	0.493
Mallomonas alpina (CH)	2.1	0.493
Navicula tripunctata (DI)	2.1	0.493
Nitzschia palea (DI)	2.1	0.493
Phacus suecicus var. oidion (EU)	2.1	0.493

Table F-3. (cont'd.)

Portage Marsh (PM1)	Species Present	
28-30 July	cells	percent
Achnanthes exigua (DI)	1.0	0.246
Achnanthes minutissima (DI)	1.0	0.246
Amphora ovalis (DI)	1.0	0.246
Amphora ovalis var. pediculus (DI)	1.0	0.246
Cocconeis placentula (DI)	1.0	0.246
Cyclotella comta (DI)	1.0	0.246
Cyclotella ocellata (DI)	1.0	0.246
Denticula elegans (DI)	1.0	0.246
Fragilaria construens var. binodis (DI)	1.0	0.246
Gomphonema angustatum (DI)	1.0	0.246
Gomphonema parvulum (DI)	1.0	0.246
Lagerheimia ciliata (GR)	1.0	0.246
Navicula cryptocephala (DI)	1.0	0.246
Navicula gregaria (DI)	1.0	0.246
Navicula menisculus var. upsaliensis (DI)	1.0	0.246
Nitzschia diserta (DI)	1.0	0.246
Nitzschia filiformis (DI)	1.0	0.246
Nitzschia sublinearis (DI)	1.0	0.246
Nitzschia vermicularis (DI)	1.0	0.246
Oscillatoria retzii (BG)	1.0	0.246
Stephanodiscus hantzschii (DI)	1.0	0.246
Stephanodiscus niagarae (DI)	1.0	0.246
Synedra pulchella (DI)	1.0	0.246
Tetraedron arthrodesmiforme (GR)	1.0	0.246
Species Total	56	

Portage Marsh (PM2)		
Tabellaria fenestrata (DI)	86.9	25.697
Fragilaria crotonensis (DI)	70.2	20.743
Asterionella formosa (DI)	37.7	11.146
Fragilaria construens var. venter (DI)	34.6	10.217
Gloeocystis planctonica (BG)	20.9	6.192
Ulothrix subconstricta (GR)	13.6	4.025
Scenedesmus quadricauda var. longispina (GR)	12.6	3.715
Micractinium pusillum (GR)	8.4	2.477
Pediastrum tetras (GR)	8.4	2.477
Fragilaria pinnata var. intercedens (DI)	6.3	1.858
Cyclotella michiganiana (DI)	5.2	1.548
Trochiscia sp (GR)	4.2	1.238
Oocystis parva (GR)	4.2	1.238
Amphora ovalis (DI)	3.1	0.929
Cyclotella stelligera (DI)	3.1	0.929

Table F-3. (cont'd.)

Portage Marsh (PM2) 28-30 July	Species Present cells	 percent
Stephanodiscus alpinus (DI)	3.1	0.929
Nitzschia fonticola (DI)	2.1	0.619
Stephanodiscus minutus (DI)	2.1	0.619
Stephanodiscus niagarae (DI)	2.1	0.619
Cyclotella ocellata (DI)	1.0	0.310
Diatoma tenue (DI)	1.0	0.310
Fragilaria vaucheriae (DI)	1.0	0.310
Mallomonas caudata (CH)	1.0	0.310
Oscillatoria limmetica (BG)	1.0	0.310
Rhizosolenia gracilis (DI)	1.0	0.310
Stephanodiscus subtilis (DI)	1.0	0.310
Stephanodiscus tenuis (DI)	1.0	0.310
Tetraedron minimum (GR)	1.0	0.310
Species Total	28	

Table F-4. Cell counts (cells/ml), percent abundance and species enumeration of algal taxa in northern Green Bay (Lake Michigan) from eight stations on 7-8 September, 1974.

Big Bay de Noc 7-8 September	Species Present cells	 percent
Fragilaria crotonensis (DI)	340.3	29.926
Anacystis incerta (BG)	328.8	28.913
Coccomyxa minor (GR)	173.8	15.285
Gloeocystis planctonica (GR)	46.1	4.052
Anacystis thermalis (BG)	45.0	3.959
Gomphosphaeria aponina (BG)	33.5	2.947
Asterionella formosa (DI)	29.3	2.578
Cyclotella michiganiana (DI)	29.3	2.578
Oocystis parva (GR)	22.0	1.934
Tabellaria flocculosa (DI)	11.5	1.013
Coelastrum microporum (GR)	8.4	0.737
Melosira granulata (DI)	8.4	0.737
Synedra filiformis (DI)	5.2	0.460
Tetraedron minimum (GR)	5.2	0.460
Nephrocytium agardhianum (GR)	4.2	0.368
Rhizosolenia eriensis (DI)	4.2	0.368
Scenedesmus denticulatus (GR)	4.2	0.368
Scenedesmus quadricauda var. longispina (GR)	4.2	0.368
Stephanodiscus niagarae (DI)	4.2	0.368
Tabellaria fenestrata (DI)	4.2	0.368
Cyclotella comta (DI)	3.1	0.276
Oscillatoria retzii (BG)	3.1	0.276
Amphipleura pellucida (DI)	2.1	0.184
Cyclotella stelligera (DI)	2.1	0.184
Undetermined flagellate sp. #1 (UN)	2.1	0.184
Nitzschia acicularis (DI)	2.1	0.184
Nitzschia fonticola (DI)	2.1	0.184
Nitzschia palea (DI)	2.1	0.184
Oscillatoria limnetica (BG)	2.1	0.184
Amphora ovalis (DI)	1.0	0.092
Cosmarium sp. #1 (GR)	1.0	0.092
Nitzschia bacata (DI)	1.0	0.092
Stephanodiscus alpinus (DI)	1.0	0.092
Species Total	33	
Upper Green Bay (OW1)		
Gomphosphaeria wichurae (BG)	314.2	46.584
Oscillatoria retzii (BG)	192.7	28.571
Fragilaria crotonensis (DI)	45.0	6.677

Table F-4. (cont'd.)

Upper Green Bay - (OW1)	Species Present	
7-8 September	cells	percent
Asterionella formosa (DI)	22.0	3.261
Mougeotia sp. #1 (GR)	22.0	3.261
Anabaena flos-aquae (BG)	20.9	3.106
Ulothrix sp. #1 (GR)	8.4	1.242
Stephanodiscus minutus (DI)	7.3	1.087
Amphipleura pellucida (DI)	6.3	0.932
Anacystis thermalis (BG)	4.2	0.621
Oocystis parva (GR)	4.2	0.621
Synedra filiformis (DI)	4.2	0.621
Tabellaria fenestrata (DI)	4.2	0.621
Oscillatoria bornetii (BG)	3.1	0.466
Rhizosolenia gracilis (DI)	3.1	0.466
Synedra demerarae (DI)	3.1	0.466
Ankistrodesmus gelifactum (GR)	2.1	0.311
Achnanthes clevei var. rostrata (DI)	1.0	0.155
Cocconeis placentula (DI)	1.0	0.155
Cyclotella michiganiana (DI)	1.0	0.155
Melosira granulata (DI)	1.0	0.155
Mallomonas pseudocoronata (CH)	1.0	0.155
Stephanodiscus alpinus (DI)	1.0	0.155
Stephanodiscus niagarae (DI)	1.0	0.155
Species Total	24	
Middle Green Bay - (Menominee-offshore)		
Oscillatoria retzii (BG)	298.5	31.353
Mougeotia sp. #1 (GR)	257.6	27.063
Diatoma tenue var. elongatum (DI)	131.9	13.861
Anacystis incerta (BG)	104.7	11.001
Fragilaria capucina (DI)	59.7	6.271
Anabaena flos-aquae (BG)	20.9	2.200
Tabellaria fenestrata (DI)	13.6	1.430
Asterionella formosa (DI)	9.4	0.990
Anacystis thermalis (BG)	8.4	0.880
Nephrocytium agardhianum (GR)	8.4	0.880
Oocystis parva (GR)	8.4	0.880
Rhizosolenia gracilis (DI)	7.3	0.770
Stephanodiscus niagarae (DI)	5.2	0.550
Nitzschia holsatica (DI)	4.2	0.440
Ankistrodesmus gelifactum (GR)	3.1	0.330
Amphipleura pellucida (DI)	3.1	0.330
Stephanodiscus minutus (DI)	2.1	0.220
Cosmarium sp. #1 (GR)	1.0	0.110

Table F-4. (cont'd.)

Middle Green Bay - (Menominee-offshore)	Species Present	
7-8 September	cells	percent
Ceratium hirundinella (DN)	1.0	0.110
Lagerheimia ciliata (GR)	1.0	0.110
Oocystis questionable spp (GR)	1.0	0.110
Staurastrum paradoxum (GR)	1.0	0.110
Species Total	22	

Gladstone (G)

Asterionella formosa (DI)	209.4	25.478
Melosira granulata (DI)	103.7	12.611
Fragilaria crotonensis (DI)	100.5	12.229
Fragilaria capucina (DI)	90.1	10.955
Gloeocystis planctonica (GR)	58.6	7.134
Stephanodiscus niagarae (DI)	45.0	5.478
Stephanodiscus alpinus (DI)	38.7	4.713
Anabaena flos-aquae (BG)	18.8	2.293
Cyclotella michiganiana (DI)	17.8	2.166
Stephanodiscus tenuis (DI)	17.8	2.166
Oocystis parva (GR)	16.8	2.038
Oscillatoria retzii (BG)	13.6	1.656
Stephanodiscus minutus (DI)	12.6	1.529
Tabellaria fenestrata (DI)	11.5	1.401
Fragilaria construens var. venter (DI)	10.5	1.274
Achnanthes lanceolata (DI)	4.2	0.510
Rhizosolenia gracilis (DI)	4.2	0.510
Scenedesmus denticulatus (GR)	4.2	0.510
Synedra filiformis (DI)	4.2	0.510
Amphora ovalis var. pediculus (DI)	3.1	0.382
Cyclotella comta (DI)	3.1	0.382
Cyclotella meneghiniana (DI)	3.1	0.382
Navicula subhamulata (DI)	3.1	0.382
Achnanthes clevei (DI)	2.1	0.255
Achnanthes questionable sp. #1 (DI)	2.1	0.255
Amphipleura pellucida (DI)	2.1	0.255
Cyclotella stelligera (DI)	2.1	0.255
Mallomonas alpina (CH)	2.1	0.255
Nitzschia palea (DI)	2.1	0.255
Achnanthes deflexa (DI)	1.0	0.127
Amphora ovalis (DI)	1.0	0.127
Amphiprora ornata (DI)	1.0	0.127
Cymbella sinuata var. antiqua (DI)	1.0	0.127
Cymbella ventricosa (DI)	1.0	0.127
Cyclotella ocellata (DI)	1.0	0.127

Table F-4. (cont'd.)

Gladstone (G) 7-8 September	Species Present cells	 percent
Navicula bicephala (DI)	1.0	0.127
Nitzschia bacata (DI)	1.0	0.127
Nitzschia capitellata (DI)	1.0	0.127
Nitzschia dissipata (DI)	1.0	0.127
Nitzschia fonticola (DI)	1.0	0.127
Nitzschia fonticola var. pelagica (DI)	1.0	0.127
Nitzschia paleacea (DI)	1.0	0.127
Staurastrum paradoxum (GR)	1.0	0.127
Species Total	43	
Escanaba (E)		
Fragilaria crotonensis (DI)	577.0	44.364
Asterionella formosa (DI)	166.5	12.802
Fragilaria construens var. venter (DI)	124.6	9.581
Melosira granulata (DI)	94.2	7.246
Stephanodiscus niagarae (DI)	40.8	3.140
Tabellaria fenestrata (DI)	31.4	2.415
Undetermined green filament sp. #1 (GR)	27.2	2.093
Gomphosphaeria aponina (BG)	25.1	1.932
Stephanodiscus alpinus (DI)	20.9	0.610
Ulothrix sp. #1 (GR)	20.9	1.610
Oocystis parva (GR)	18.8	1.449
Cyclotella michiganiana (DI)	17.8	1.369
Stephanodiscus minutus (DI)	14.7	1.127
Amphora ovalis var. pediculus (DI)	11.5	0.886
Anabaena sp. #2 (BG)	10.5	0.805
Oscillatoria retzii (BG)	9.4	0.725
Scenedesmus quadricauda var. longispina (GR)	8.4	0.644
Fragilaria capucina (DI)	6.3	0.483
Ankistrodesmus gelifactum (GR)	5.2	0.403
Undetermined flagellate sp. #1 (UN)	5.2	0.403
Fragilaria construens var. pumila (DI)	5.2	0.403
Achnanthes exigua (DI)	4.2	0.322
Amphora ovalis (DI)	4.2	0.322
Nitzschia bacata (DI)	4.2	0.322
Nitzschia fonticola (DI)	4.2	0.322
Achnanthes questionable sp. #1 (DI)	3.1	0.242
Eucocconeis flexella (DI)	3.1	0.242
Navicula radiosa var. tenella (DI)	3.1	0.242
Nitzschia palea (DI)	3.1	0.242
Achnanthes clevei (DI)	2.1	0.161
Amphipleura pellucida (DI)	2.1	0.161

Table F-4. (cont'd.)

Escanaba (E) 7-8 September	Species Present cells	 percent
Cymbella ventricosa (DI)	2.1	0.161
Cocconeis placentula (DI)	2.1	0.161
Cyclotella comta (DI)	2.1	0.161
Cyclotella meneghiniana (DI)	2.1	0.161
Oscillatoria limnetica (BG)	2.1	0.161
Peridinium sp. #1 (DN)	2.1	0.161
Stephanodiscus tenuis (DI)	2.1	0.161
Achnanthes exigua var. constricta (DI)	1.0	0.081
Achnanthes lanceolata (DI)	1.0	0.081
Cymbella microcephala (DI)	1.0	0.081
Diatoma tenue var. elongatum (DI)	1.0	0.081
Mallomonas alpina (CH)	1.0	0.081
Mallomonas caudata (CH)	1.0	0.081
Mallomonas pseudocoronata (CH)	1.0	0.081
Navicula reinhardtii (DI)	1.0	0.081
Nitzschia capitellata (DI)	1.0	0.081
Synedra filiformis (DI)	1.0	0.081
Species Total	48	

Menominee - nearshore (M)		
Oscillatoria retzii (BG)	412.6	47.527
Diatoma tenue var. elongatum (DI)	180.1	20.748
Gomphosphaeria lacustris (BG)	62.8	7.238
Mougeotia sp. #1 (GR)	40.8	4.704
Anabaena sp. #2 (BG)	27.2	3.136
Melosira granulata (DI)	26.2	3.016
Fragilaria pinnata (DI)	17.8	2.051
Oscillatoria limnetica(BG)	14.7	1.689
Ankistrodesmus gelifactum (GR)	11.5	1.327
Fragilaria construens var. venter (DI)	9.4	1.086
Stephanodiscus minutus (DI)	9.4	1.086
Synedra filiformis (DI)	8.4	0.965
Asterionella formosa (DI)	7.3	0.844
Rhizosolenia gracilis (DI)	6.3	0.724
Stephanodiscus tenuis (DI)	6.3	0.724
Stephanodiscus niagarae (DI)	5.2	0.603
Ulothrix subconstricta (GR)	5.2	0.603
Undetermined flagellate sp. #1 (UN)	4.2	0.483
Melosira varians (DI)	3.1	0.362
Stephanodiscus alpinus (DI)	3.1	0.362
Amphora ovalis var. pediculus (DI)	1.0	0.121
Cyclotella stelligera (DI)	1.0	0.121

Table F-4. (cont'd.)

Menominee - nearshore (M)	Species Present	
7-8 September	cells	percent
Navicula latens (DI)	1.0	0.121
Nitzschia acicularis (DI)	1.0	0.121
Stephanodiscus subtilis (DI)	1.0	0.121
Tabellaria flocculosa (DI)	1.0	0.121
Species Total	26	
Portage Marsh (PM1)		
Fragilaria crotonensis (DI)	248.2	20.378
Fragilaria capucina (DI)	162.3	13.328
Fragilaria construens var. venter (DI)	159.2	13.070
Fragilaria construens var. pumila (DI)	117.3	9.630
Fragilaria construens (DI)	116.2	9.544
Fragilaria construens var. binodis (DI)	59.7	4.901
Melosira granulata (DI)	46.1	3.783
Asterionella formosa (DI)	32.5	2.666
Stephanodiscus tenuis (DI)	25.1	2.064
Tabellaria fenestrata var. intermedia (DI)	25.1	2.064
Cocconeis placentula (DI)	24.1	1.978
Cyclotella michiganiana (DI)	14.7	1.204
Fragilaria intermedia (DI)	14.7	1.204
Stephanodiscus minutus (DI)	14.7	1.204
Achnanthes lanceolata var. dubia (DI)	13.6	1.118
Cyclotella meneghiniana (DI)	11.5	0.946
Fragilaria pinnata var. intercedens (DI)	11.5	0.946
Gomphonema parvulum (DI)	8.4	0.688
Navicula questionable sp. #1 (DI)	8.4	0.688
Achnanthes hungarica (DI)	7.3	0.602
Amphora ovalis var. pediculus (DI)	7.3	0.602
Nitzschia bacata (DI)	7.3	0.602
Achnanthes questionable sp. #1 (DI)	5.2	0.430
Nitzschia amphibia (DI)	5.2	0.430
Nitzschia dissipata (DI)	5.2	0.430
Oscillatoria retzii (BG)	5.2	0.430
Achnanthes exigua var. constricta (DI)	4.2	0.344
Navicula capitata (DI)	4.2	0.344
Navicula radiosa var. tenella (DI)	4.2	0.344
Scenedesmus denticulatus (GR)	4.2	0.344
Navicula cryptocephala (DI)	3.1	0.258
Navicula latens (DI)	3.1	0.258
Amphora neglecta (DI)	0.1	0.086
Amphiprora ornata (DI)	0.1	0.086
Cyclotella comta (DI)	0.1	0.086

Table F-4 (cont'd.)

Portage Marsh (PM1) 7-8 September	Species Present cells	 percent
Fragilaria leptostauron (DI)	1.0	0.086
Nitzschia palea (DI)	1.0	0.086
Nitzschia paleacea (DI)	1.0	0.086
Stephanodiscus alpinus (DI)	1.0	0.086
Stephanodiscus niagarae (DI)	1.0	0.086
Stephanodiscus subtilis (DI)	1.0	0.086
Synedra pulchella (D()	1.0	0.086
Achnanthes clevei (DI)	1.0	0.086
Achnanthes linearis (DI)	1.0	0.086
Eunotia arcus var. bidens (DI)	1.0	0.086
Fragilaria sp. #1 (DI)	1.0	0.086
Fragilaria vaucheriae (DI)	1.0	0.086
Gomphonema gracile (DI)	1.0	0.086
Gyrosigma acuminatum (DI)	1.0	0.086
Mallomonas caudata (CH)	1.0	0.086
Navicula minima (DI)	1.0	0.086
Navicula pupula var. capitata (DI)	1.0	0.086
Navicula stroesei (DI)	1.0	0.086
Nitzschia acuta (DI)	1.0	0.086
Nitzschia fonticola (DI)	1.0	0.086
Nitzschia sp. #2 (DI)	1.0	0.086
Pinnularia questionable sp. #1 (DI)	1.0	0.086
Rhoicosphenia curvata (DI)	1.0	0.086
Synedra filiformis (DI)	1.0	0.086
	59	
Portage Marsh (PM2)		
Fragilaria crotonensis (DI)	272.3	34.392
Asterionella formosa (DI)	89.0	11.243
Melosira granulata (DI)	85.9	10.847
Fragilaria capucina (DI)	66.0	8.333
Anacystis incerta (BG)	52.4	6.614
Stephanodiscus niagarae (DI)	42.9	5.423
Oscillatoria retzii (BG)	37.7	4.762
Stephanodiscus minutus (DI)	20.9	2.646
Cyclotella michiganiana (DI)	15.7	1.984
Pediastrum duplex var. cohaerens (GR)	14.7	1.852
Tabellaria fenestrata (DI)	14.7	1.852
Stephanodiscus alpinus (DI)	13.6	1.720
Oocystis parva (GR)	9.4	1.190
Anacystis thermalis (BG)	8.4	1.058
Gloeocystis planctonica (GR)	8.4	1.058
Amphipleura (DI)	6.3	0.794

Table F-4. (cont'd.)

Portage Marsh (PM2) 7-8 September	Species Present cells	 percent
Anabaena sp. #2 (BG)	5.2	0.661
Stephanodiscus binderanus (DI)	4.2	0.529
Cyclotella comta (DI)	3.1	0.397
Amphora ovalis (DI)	2.1	0.265
Mallomonas alpina (CH)	2.1	0.265
Navicula pupula (DI)	2.1	0.265
Achnanthes minutissima (DI)	1.0	0.132
Amphora ovalis var. pediculus (DI)	1.0	0.132
Cymbella ventricosa (DI)	1.0	0.132
Cyclotella meneghiniana (DI)	1.0	0.132
Cyclotella ocellata (DI)	1.0	0.132
Mallomonas caudata (CH)	1.0	0.132
Mallomonas pseudocoronata (CH)	1.0	0.132
Neidium dubium (DI)	1.0	0.132
Nitzschia dissipata (DI)	1.0	0.132
Nitzschia filiformis (DI)	1.0	0.132
Nitzschia paleacea (DI)	1.0	0.132
Stephanodiscus tenuis (DI)	1.0	0.132
Synedra demerarae (DI)	1.0	0.132
Tetraedron minimum (GR)	1.0	0.132
Species Total	36	

Table F-5. Cell counts (cells/ml), percent abundance and species enumeration of algal taxa in northern Green Bay (Lake Michigan) from eight stations on 26-27 October, 1974.

Big Bay de Noc 26-27 October	Species Present	
	cells	percent
Asterionella formosa (DI)	1518.4	59.232
Fragilaria crotonensis (DI)	328.8	12.827
Synedra demerarae (DI)	121.5	4.739
Fragilaria capucina (DI)	88.0	3.431
Anacystis cyanea (BG)	83.8	3.268
Oscillatoria retzii (BG)	64.9	2.533
Diatoma tenue var. elongatum (DI)	52.4	2.042
Tabellaria fenestrata (DI)	41.9	1.634
Crucigenia quadrata (GR)	25.1	0.980
Rhizosolenia eriensis (DI)	23.0	0.899
Ulothrix sp. #1 (GR)	23.0	0.899
Anacystis thermalis (BG)	20.9	0.817
Cyclotella michiganiana (DI)	20.9	0.817
Stephanodiscus niagarae (DI)	18.8	0.735
Oocystis parva (GR)	16.8	0.654
Cyclotella kutzingiana (DI)	12.6	0.490
Undetermined flagellate sp. #1	12.6	0.490
Cyclotella comta (DI)	10.5	0.408
Synedra filiformis (DI)	8.4	0.327
Amphora ovalis (DI)	6.3	0.245
Amphipleura pellucida (DI)	6.3	0.245
Fragilaria pinnata (DI)	6.3	0.245
Rhizosolenia gracilis (DI)	6.3	0.245
Cyclotella meneghiniana (DI)	4.2	0.163
Nitzschia bacata (DI)	4.2	0.163
Nitzschia palea (DI)	4.2	0.163
Oscillatoria limnetica (BG)	4.2	0.163
Stephanodiscus minutus (DI)	4.2	0.163
Achnanthes lanceolata (DI)	2.1	0.082
Ankistrodesmus gelifactum (GR)	2.1	0.082
Amphora ovalis var. pediculus (DI)	2.1	0.082
Dinoflagellate sp. #1	2.1	0.082
Diatoma tenue (DI)	2.1	0.082
Diatoma vulgaris (DI)	2.1	0.082
Melosira italica (DI)	2.1	0.082
Mallomonas alpina (CH)	2.1	0.082
Navicula questionable sp. #1 (DI)	2.1	0.082
Nitzschia longissima var. reversa (DI)	2.1	0.082
Stephanodiscus alpinus (DI)	2.1	0.082
Tetraedron minimum (GR)	2.1	0.082
Species Total	40	

Table F-5. (cont'd.)

Upper Green Bay (OW1)	Species Present	
26-27 October	cells	percent
Asterionella formosa (DI)	557.1	25.775
Oscillatoria retzii (BG)	444.0	20.543
Fragilaria crotonensis (DI)	431.4	19.961
Diatoma tenue var. elongatum (DI)	199.0	9.205
Anacystis cyanea (BG)	146.6	6.783
Fragilaria capucina (DI)	77.5	3.585
Stephanodiscus alpinus (DI)	67.0	3.101
Crucigenia quadrata (GR)	41.9	1.938
Ulothrix subconstricta (GR)	35.6	1.647
Stephanodiscus tenuis (DI)	33.5	1.550
Stephanodiscus niagarae (DI)	27.2	1.260
Mougeotia sp. #1 (GR)	14.7	0.678
Ankistrodesmus braunii (GR)	6.3	0.291
Amphora ovalis (DI)	6.3	0.291
Nitzschia confinis (DI)	6.3	0.291
Oscillatoria limnetica (BG)	6.3	0.291
Rhizosolenia gracilis (DI)	6.3	0.291
Stephanodiscus minutus (DI)	6.3	0.291
Synedra filiformis (DI)	6.3	0.291
Cyclotella comta (DI)	4.2	0.194
Melosira granulata (DI)	4.2	0.194
Tabellaria fenestrata (DI)	4.2	0.194
Achnanthes clevei var. rostrata (DI)	2.1	0.097
Amphora ovalis var. pediculus (DI)	2.1	0.097
Amphipleura pellucida (DI)	2.1	0.097
Cymatopleura solea (DI)	2.1	0.097
Cyclotella michiganiana (DI)	2.1	0.097
Fragilaria vaucheriae (DI)	2.1	0.097
Melosira distans var. alpigena (DI)	2.1	0.097
Nitzschia angustata var. acuta (DI)	2.1	0.097
Rhizosolenia eriensis (DI)	2.1	0.097
Staurastrum paradoxum (GR)	2.1	0.097
Stephanodiscus hantzschii (DI)	2.1	0.097
Synedra demerarae (DI)	2.1	0.097
Synedra ulna var. chaseana (DI)	2.1	0.097
Tetraedron minimum (GR)	2.1	0.097
Species Total	36	

Table F-5. (cont'd.)

Middle Green Bay - (Menominee-offshore) 26-27 October	Species Present cells	 percent
Oscillatoria retzii (BG)	768.6	41.657
Asterionella formosa (DI)	307.9	16.686
Gloeocystis planctonica (BG)	167.6	9.081
Stephanodiscus alpinus (DI)	138.2	7.491
Diatoma tenue var. elongatum (DI)	77.5	4.200
Melosira granulata (DI)	77.5	4.200
Ulothrix subconstricta (GR)	69.1	3.746
Fragilaria capucina (DI)	62.8	3.405
Stephanodiscus minutus(DI)	29,3	1.589
Stephanodiscus hantzschii (DI)	27.2	1.476
Borodinella sp. #1 (GR)	16.8	0.908
Fragilaria crotonensis (DI)	14.7	0.795
Fragilaria pinnata (DI)	12.6	0.681
Stephanodiscus niagarae (DI)	12.6	0.681
Oocystis questionable spp (GR)	8.4	0.454
Tabellaria fenestrata (DI)	8.4	0.454
Ankistrodesmus braunii (GR)	6.3	0.341
Cyclotella comta (DI)	6.3	0.341
Stephanodiscus tenuis(DI)	6.3	0.341
Undetermined flagellate sp. #1 (UN)	4.2	0.227
Rhizosolenia gracilis (DI)	4.2	0.227
Scenedesmus bicellularis (GR)	4.2	0.227
Synedra ulna var. chaseana (DI)	4.2	0.227
Amphora ovalis var. pediculus(DI)	2.1	0.114
Cyclotella meneghiniana (DI)	2.1	0.114
Navicula reinhardtii (DI)	2.1	0.114
Nitzschia confinis (DI)	2.1	0.114
Staurastrum paradoxum (GR)	2.1	0.114
Species Total	28	
Gladstone (G)		
Melosira granulata (DI)	504.7	22.822
Asterionella formosa (DI)	431.4	19.508
Fragilaria crotonensis (DI)	211.5	9.564
Oscillatoria retzii (BG)	169.6	7.670
Fragilaria capucina (DI)	142.4	6.439
Ulothrix sp. #1 (GR)	136.1	6.155
Stephanodiscus binderanus (BI)	125.7	5.682
Diatoma tenue var. elongatum (BI)	108.9	4.924
Tabellaria fenestrata (BI)	71.2	3.220
Fragilaria pinnata (BI)	58.6	2.652
Gomphosphaeria aponina (BG)	41.9	1.894

Table F-5. (cont'd.)

Gladstone (G)	Species Present	
26-27 October	cells	percent
Stephanodiscus niagarae (DI)	39.8	1.799
Stephanodiscus alpinus (DI)	31.4	1.420
Ulothrix sp. #2 (GR)	20.9	0.947
Anacystis thermalis (BG)	16.8	0.758
Stephanodiscus minutus (DI)	14.7	0.663
Melosira granulata var. angustissima (DI)	8.4	0.379
Oocystis parva (GR)	8.4	0.379
Rhizosolenia gracilis (DI)	8.4	0.379
Scenedesmus quadricauda (GR)	8.4	0.379
Cocconeis placentula (DI)	6.3	0.284
Rhizosolenia eriensis (DI)	6.3	0.284
Ankistrodesmus braunii (GR)	4.2	0.189
Amphora ovalis var. pediculus (DI)	4.2	0.189
Staurastrum paradoxum (GR)	4.2	0.189
Stephanodiscus hantzschii (DI)	4.2	0.189
Achnanthes exigua (DI)	2.1	0.095
Amphipleura pellucida (DI)	2.1	0.095
Cymbella microcephala (DI)	2.1	0.095
Cyclotella kutzingiana (DI)	2.1	0.095
Cyclotella meneghiniana (DI)	2.1	0.095
Cyclotella michiganiana (DI)	2.1	0.095
Dinoflagellate sp. #1 (DN)	2.1	0.095
Gomphonema angustatum (DI)	2.1	0.095
Nitzschia recta (DI)	2.1	0.095
Nitzschia sigmoidea (DI)	2.1	0.095
Synedra ulna var. chaseana (DI)	2.1	0.095
Species Total	37	
Escanaba (E)		
Asterionella formosa (DI)	456.6	24.494
Fragilaria crotonensis (DI)	289.0	15.506
Oscillatoria retzii (BG)	230.4	12.360
Diatoma tenue (DI)	207.3	11.124
Synedra demerarae (DI)	155.0	8.315
Melosira granulata (DI)	79.6	4.270
Tabellaria fenestrata var. intermedia (DI)	77.5	4.157
Ulothrix sp. #1 (GR)	73.3	3.933
Nitzschia holsatica (DI)	41.9	2.247
Stephanodiscus alpinus (DI)	41.9	2.247
Stephanodiscus niagarae (DI)	29.3	1.573
Stephanodiscus tenuis (DI)	29.3	1.573
Stephanodiscus binderanus (DI)	27.2	1.461

Table F-5. (cont'd.)

Escanaba (E)	Species Present	
26-27 October	cells	percent
Stephanodiscus minutus (DI)	18.8	1.011
Synedra ulna var. chaseana (DI)	16.8	0.899
Rhizosolenia eriensis (DI)	14.7	0.787
Cyclotella comta (DI)	8.4	0.449
Cyclotella michiganiana (DI)	8.4	0.449
Rhizosolenia gracilis (DI)	8.4	0.449
Amphipleura pellucida (DI)	6.3	0.337
Melosira italica (DI)	6.3	0.337
Stephanodiscus hantzschii (DI)	6.3	0.337
Oscillatoria bornetii (BG)	4.2	0.225
Synedra filiformis (DI)	4.2	0.225
Amphora ovalis var. pediculus (DI)	2.1	0.112
Cyclotella ocellata (DI)	2.1	0.112
Eunotia questionable sp. #1 (DI)	2.1	0.112
Gomphonema parvulum (DI)	2.1	0.112
Navicula platystoma var. pantocsekii (DI)	2.1	0.112
Navicula tuscula (DI)	2.1	0.112
Nitzschia angustata var. acuta (DI)	2.1	0.112
Nitzschia bacata (DI)	2.1	0.112
Nitzschia fonticola (DI)	2.1	0.112
Staurastrum paradoxum (GR)	2.1	0.112
Stephanodiscus subtilis (DI)	2.1	0.112
Species Total	35	
Menominee - nearshore (M)		
Oscillatoria retzii (BG)	668.1	29.897
Asterionella formosa (DI)	435.6	19.494
Fragilaria capucina (DI)	240.9	10.778
Diatoma tenue var. elongatum (DI)	234.6	10.497
Fragilaria crotonensis (DI)	115.2	5.155
Stephanodiscus alpinus (DI)	100.5	4.499
Stephanodiscus niagarae (DI)	69.1	3.093
Melosira granulata (DI)	62.8	2.812
Coelastrum microporum (BG)	50.3	2.249
Nitzschia holsatica (DI)	41.9	1.874
Stephanodiscus tenuis (DI)	35.6	1.593
Stephanodiscus binderanus (DI)	27.2	1.218
Ulothrix sp. #1 (GR)	27.2	1.218
Oocystis parva (GR)	25.1	1.125
Fragilaria pinnata (DI)	23.0	1.031
Stephanodiscus minutus (DI)	14.7	0.656
Stephanodiscus hantzschii (DI)	10.5	0.469
Scenedesmus quadricauda var. longispina (GR)	8.4	0.375

Table F-5. (cont'd.)

Menominee - nearshore (M)	Species Present	
26-27 October	cells	percent
Amphipleura pellucida (DI)	6.3	0.281
Oscillatoria bornetii (BG)	6.3	0.281
Tabellaria fenestrata (DI)	6.3	0.281
Ankistrodesmus braunii (GR)	4.2	0.187
Amphiprora ornata (DI)	4.2	0.187
Cyclotella comta (DI)	2.1	0.094
Cyclotella michiganiana (DI)	2.1	0.094
Navicula cryptocephala (DI)	2.1	0.094
Nitzschia acicularis (DI)	2.1	0.094
Rhizosolenia gracilis (DI)	2.1	0.094
Staurastrum paradoxum (GR)	2.1	0.094
Synedra filiformis (DI)	2.1	0.094
Synedra ulna var. chaseana (DI)	2.1	0.094
Species Total	31	
Portage Marsh (PM1)		
Stephanodiscus tenuis (DI)	1616.9	37.640
Asterionella formosa (DI)	896.4	20.868
Stephanodiscus subtilis (DI)	456.6	10.629
Diatoma tenue var. elongatum (DI)	230.4	5.363
Fragilaria crotonensis (DI)	190.6	4.437
Fragilaria capucina (DI)	125.7	2.925
Oscillatoria retzii (BG)	119.4	2.779
Fragilaria brevistriata var. inflata (DI)	102.6	2.389
Fragilaria construens (DI)	88.0	2.048
Fragilaria pinnata (DI)	58.6	1.365
Fragilaria construens var. venter (DI)	52.4	1.219
Stephanodiscus minutus (DI)	41.9	0.975
Nitzschia holsatica (DI)	29.3	0.683
Mallomonas tonsurata var. alpinus (CH)	18.8	0.439
Nitzschia bacata (DI)	18.8	0.439
Achnanthes lanceolata (DI)	16.8	0.390
Achnanthes minutissima (DI)	14.7	0.341
Melosira varians (DI)	12.6	0.293
Navicula cryptocephala (DI)	12.6	0.293
Gomphonema parvulum (DI)	10.5	0.244
Rhizosolenia eriensis (DI)	10.5	0.244
Tabellaria fenestrata (DI)	10.5	0.244
Diatoma tenue (DI)	8.4	0.195
Undetermined flagellate sp. #1	8.4	0.195
Nitzschia dissipata (DI)	8.4	0.195
Oocystis questionable spp (GR)	8.4	0.195

Table F-5. (cont'd.)

Portage Marsh (PM1) 26-27 October	Species Present	
	cells	percent
Stephanodiscus subsalsus(DI)	8.4	0.195
Synedra filiformis (DI)	8.4	0.195
Ulothrix sp. #1 (GR)	8.4	0.195
Cyclotella michiganiana (DI)	6.3	0.146
Dinoflagellate sp. #1 (DN)	6.3	0.146
Nitzschia filiformis (DI)	6.3	0.146
Synedra ulna (DI)	6.3	0.146
Amphora ovalis (DI)	4.2	0.098
Amphora ovalis var. pediculus (DI)	4.2	0.098
Amphiprora ornata (DI)	4.2	0.098
Cocconeis placentula (DI)	4.2	0.098
Cyclotella comta (DI)	4.2	0.098
Melosira granulata (DI)	4.2	0.098
Navicula menisculus var. upsaliensis (DI)	4.2	0.098
Rhizosolenia gracilis (DI)	4.2	0.098
Stephanodiscus alpinus (DI)	4.2	0.098
Synedra ulna var. chaseana (DI)	4.2	0.098
Achnanthes clevei var. rostrata (DI)	2.1	0.049
Cymbella ventricosa (DI)	2.1	0.049
Cyclotella meneghiniana (DI)	2.1	0.049
Eucocconeis flexella (DI)	2.1	0.049
Fragilaria vaucheriae (DI)	2.1	0.049
Navicula anglica var. subsalsa (DI)	2.1	0.049
Navicula capitata (DI)	2.1	0.049
Navicula radiosa (DI)	2.1	0.049
Navicula radiosa var. tenella (DI)	2.1	0.049
Navicula rhynchocephala (DI)	2.1	0.049
Nitzschia fonticola (DI)	2.1	0.049
Nitzschia recta (DI)	2.1	0.049
Rhoicosphenia curvata (DI)	2.1	0.049
Stauroneis questionable sp. #1 (GR)	2.1	0.049
Staurastrum paradoxum (GR)	2.1	0.049
Stephanodiscus hantzschii (DI)	2.1	0.049
Stephanodiscus niagarae (DI)	2.1	0.049
Species Total	60	

Portage Marsh (PM2)		
Asterionella formosa (DI)	735.1	32.865
Oscillatoria retzii (BG)	379.1	16.948
Fragilaria crotonensis (DI)	335.1	14.981
Diatoma tenue var. elongatum (DI)	284.8	12.734
Melosira granulata (DI)	102.6	4.588

Table F-5. (cont'd.)

Portage Marsh (PM2)	Species Present	
26-27 October	cells	percent
Fragilaria pinnata (DI)	75.4	3.371
Stephanodiscus alpinus (DI)	71.2	2.184
Tabellaria fenestrata var. intermedia (DI)	37.7	1.685
Stephanodiscus niagarae (DI)	33.5	1.498
Scenedesmus quadricauda var. longispina (DI)	20.9	0.936
Amphipleura pellucida (DI)	18.8	0.843
Ulothrix subconstricta (GR)	18.8	0.843
Nitzschia holsatica (DI)	14.7	0.655
Stephanodiscus minutus (DI)	14.7	0.655
Cyclotella michiganiana (DI)	12.6	0.562
Synedra filiformis (DI)	10.5	0.468
Anacystis thermalis (BG)	8.4	0.375
Oocystis questionable spp (GR)	8.4	0.375
Melosira italica (DI)	6.3	0.281
Amphora ovalis var. pediculus (DI)	4.2	0.187
Cyclotella comta (DI)	4.2	0.187
Cyclotella ocellata (DI)	4.2	0.187
Epithemia sorex (DI)	4.2	0.187
Melosira distans var. alpigena (DI)	4.2	0.187
Rhizosolenia eriensis (DI)	4.2	0.187
Rhizosolenia gracilis (DI)	4.2	0.187
Stephanodiscus subtilis (DI)	4.2	0.187
Stephanodiscus Tenuis (DI)	4.2	0.187
Cymatopleura solea (DI)	2.1	0.094
Navicula cryptocephala (DI)	2.1	0.094
Navicula tuscula (DI)	2.1	0.094
Nitzschia fonticola (DI)	2.1	0.094
Nitzschia sp. #10 (DI)	2.1	0.094
Species Total	33	